

APPENDIX G

**STATISTICAL AND GEOCHEMICAL EVALUATIONS
OF SITE METALS DATA**

**STATISTICAL
(TIERS I AND II)**

Statistical Comparison of Site and Background Data Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X Fort McClellan, Alabama

1.0 Introduction

This report provides the Tier 1 and Tier 2 (Shaw E&I, 2003) site-to-background comparison results for Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X, at Fort McClellan in Calhoun County, Alabama. In the first step of the comparison, the maximum detected concentration (MDC) of each element is compared to two times the arithmetic mean of the background data (SAIC, 1998). Any metal that has an MDC greater than the background screening value is carried forward for Tier 2 evaluation, which includes the Slippage Test and the Wilcoxon Rank Sum Test (WRS). If either or both of these statistical test cannot be done, the evaluation will include the Hot Measurement Test.

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 through 5, and described in more detail in the following sections. Site samples used in the site-to-background comparison include 11 surface soil samples (0 to 1 foot below ground surface [bgs]), 11 subsurface soil samples (2 to 12 feet bgs), 4 groundwater samples, 6 sediment samples, and 6 surface water samples that were collected at the site.

Background distributions and screening values have been established for target analyte list metals in surface soil, subsurface soil, groundwater, sediment, and surface water for Fort McClellan (SAIC, 1998).

2.0 Comparison Methodology

This section describes the statistical techniques that were employed in the Range 23A site-to-background comparison.

2.1 Statistical Procedures

Contamination can be caused by a variety of processes that yield different spatial distributions of elevated contaminant concentrations. Slight but pervasive contamination can occur from non-point-source releases, and can result in slight increases in contaminant concentrations in a large percentage of samples. Localized, or “hot-spot,” contamination can result in elevated concentrations in a small percentage of the total number of site samples. No single two-sample statistical comparison test is sensitive to both of these modes of contamination. For this reason,

Table 1

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Surface Soil
Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	11 / 11	Passed	NA	NA	NA	
Antimony	0 / 11	NA	NA	NA	NA	
Arsenic	11 / 11	Failed	Passed	Failed	NA	Yes
Barium	11 / 11	Passed	NA	NA	NA	
Beryllium	3 / 11	Passed	NA	NA	NA	
Cadmium	0 / 11	NA	NA	NA	NA	
Calcium	9 / 11	Passed	NA	NA	NA	
Chromium	11 / 11	Passed	NA	NA	NA	
Cobalt	7 / 11	Passed	NA	NA	NA	
Copper	11 / 11	Failed	Passed	Failed	NA	Yes
Iron	11 / 11	Passed	NA	NA	NA	
Lead	11 / 11	Passed	NA	NA	NA	
Magnesium	11 / 11	Failed	Passed	Failed	NA	Yes
Manganese	11 / 11	Passed	NA	NA	NA	
Mercury	1 / 11	Passed	NA	NA	NA	
Nickel	4 / 11	Failed	Passed	NA ^d	Passed	
Potassium	11 / 11	Failed	Passed	Failed	NA	Yes
Selenium	4 / 11	Failed	Passed	NA ^d	Failed	Yes
Silver	6 / 11	Failed	Passed	Failed	NA	Yes
Sodium	11 / 11	Passed	NA	NA	NA	
Thallium	0 / 11	NA	NA	NA	NA	
Vanadium	11 / 11	Passed	NA	NA	NA	
Zinc	11 / 11	Failed	Passed	Failed	NA	Yes

NA = not applicable

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or Wilcoxon Rank Sum (WRS) test cannot be performed.

d WRS test is not performed on data sets containing 50% or more nondetects.

Table 2

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Subsurface Soil
Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	11 / 11	Failed	Passed	Passed	NA	
Antimony	0 / 11	NA	NA	NA	NA	
Arsenic	11 / 11	Failed	Passed	Failed	NA	Yes
Barium	11 / 11	Failed	Passed	Passed	NA	
Beryllium	3 / 11	Failed	Passed	NA ^e	Passed	
Cadmium	2 / 11	Failed	Passed	NA ^e	Failed	Yes
Calcium	5 / 11	Passed	NA	NA	NA	
Chromium	11 / 11	Passed	NA	NA	NA	
Cobalt	7 / 11	Failed	Passed	Passed	NA	
Copper	11 / 11	Failed	Passed	Failed	NA	Yes
Iron	11 / 11	Passed	NA	NA	NA	
Lead	11 / 11	Failed	Passed	Passed	NA	
Magnesium	11 / 11	Failed	Passed	Failed	NA	Yes
Manganese	11 / 11	Failed	Passed	Passed	NA	
Mercury	5 / 11	Failed	Passed	NA ^e	Failed	Yes
Nickel	7 / 11	Failed	Passed	Passed	NA	
Potassium	11 / 11	Failed	Passed	Failed	NA	Yes
Selenium	1 / 11	Failed	NA ^d	NA ^e	Failed	Yes
Silver	6 / 11	Failed	NA ^d	Failed	Failed	Yes
Sodium	11 / 11	Passed	NA	NA	NA	
Thallium	1 / 11	Failed	Passed	NA ^e	Passed	
Vanadium	11 / 11	Passed	NA	NA	NA	
Zinc	11 / 11	Failed	Passed	Failed	NA	Yes

NA = not applicable

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or Wilcoxon Rank Sum (WRS) test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing 50% or more nondetects.

Table 3

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Groundwater
Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	4 / 4	Failed	Passed	NA ^e	Failed	Yes
Antimony	0 / 4	NA	NA	NA	NA	
Arsenic	2 / 4	Passed	NA	NA	NA	
Barium	4 / 4	Failed	Passed	NA ^e	Passed	
Beryllium	1 / 4	Failed	NA ^d	NA ^e	Passed	
Cadmium	0 / 4	NA	NA	NA	NA	
Calcium	3 / 4	Passed	NA	NA	NA	
Chromium	1 / 4	Failed	NA ^d	NA ^e	Passed	
Cobalt	2 / 4	Failed	Passed	NA ^e	Failed	Yes
Copper	1 / 4	Failed	Passed	NA ^e	Passed	
Iron	4 / 4	Failed	Passed	NA ^e	Passed	
Lead	1 / 4	Failed	NA ^d	NA ^e	Passed	
Magnesium	3 / 4	Passed	NA	NA	NA	
Manganese	4 / 4	Failed	Passed	NA ^e	Passed	
Mercury	1 / 4	Failed	NA ^d	NA ^e	Failed	Yes
Nickel	2 / 4	Failed	NA ^d	NA ^e	Failed	Yes
Potassium	0 / 4	NA	NA	NA	NA	
Selenium	0 / 4	NA	NA	NA	NA	
Silver	0 / 4	NA	NA	NA	NA	
Sodium	3 / 4	Failed	Passed	NA ^e	Passed	
Thallium	0 / 4	NA	NA	NA	NA	
Vanadium	1 / 4	Failed	NA ^d	NA ^e	Passed	
Zinc	1 / 4	Passed	NA	NA	NA	

NA = not applicable

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or Wilcoxon Rank Sum (WRS) test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing less than 5 samples.

Table 4

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Sediment
Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	6 / 6	Failed	Passed	Failed	NA	Yes
Antimony	0 / 6	NA	NA	NA	NA	
Arsenic	6 / 6	Passed	NA	NA	NA	
Barium	6 / 6	Passed	NA	NA	NA	
Beryllium	1 / 6	Passed	NA	NA	NA	
Cadmium	0 / 6	NA	NA	NA	NA	
Calcium	6 / 6	Failed	Passed	Passed	NA	
Chromium	6 / 6	Passed	NA	NA	NA	
Cobalt	6 / 6	Passed	NA	NA	NA	
Copper	6 / 6	Passed	NA	NA	NA	
Iron	6 / 6	Passed	NA	NA	NA	
Lead	6 / 6	Passed	NA	NA	NA	
Magnesium	6 / 6	Passed	NA	NA	NA	
Manganese	6 / 6	Failed	Passed	Passed	NA	
Mercury	1 / 6	Passed	NA	NA	NA	
Nickel	6 / 6	Passed	NA	NA	NA	
Potassium	6 / 6	Passed	NA	NA	NA	
Selenium	3 / 6	Failed	Passed	NA ^d	Passed	
Silver	0 / 6	NA	NA	NA	NA	
Sodium	6 / 6	Passed	NA	NA	NA	
Thallium	0 / 6	NA	NA	NA	NA	
Vanadium	6 / 6	Passed	NA	NA	NA	
Zinc	6 / 6	Passed	NA	NA	NA	

NA = not applicable

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or Wilcoxon Rank Sum (WRS) test cannot be performed.

d WRS test is not performed on data sets containing 50% or more nondetects.

Table 5

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Surface Water
Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation ^a	Slippage Test ^b	Wilcoxon Rank Sum Test ^b	Hot Measurement Test ^{b,c}	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	6 / 6	Passed	NA	NA	NA	
Antimony	0 / 6	NA	NA	NA	NA	
Arsenic	2 / 6	Failed	Passed	NA ^e	Failed	Yes
Barium	6 / 6	Passed	NA	NA	NA	
Beryllium	0 / 6	NA	NA	NA	NA	
Cadmium	0 / 6	NA	NA	NA	NA	
Calcium	6 / 6	Passed	NA	NA	NA	
Chromium	0 / 6	NA	NA	NA	NA	
Cobalt	3 / 6	Failed	NA ^d	NA ^e	Passed	
Copper	0 / 6	NA	NA	NA	NA	
Iron	6 / 6	Passed	NA	NA	NA	
Lead	0 / 6	NA	NA	NA	NA	
Magnesium	6 / 6	Passed	NA	NA	NA	
Manganese	6 / 6	Passed	NA	NA	NA	
Mercury	0 / 6	NA	NA	NA	NA	
Nickel	0 / 6	NA	NA	NA	NA	
Potassium	1 / 6	Passed	NA	NA	NA	
Selenium	0 / 6	NA	NA	NA	NA	
Silver	0 / 6	NA	NA	NA	NA	
Sodium	3 / 6	Passed	NA	NA	NA	
Thallium	0 / 6	NA	NA	NA	NA	
Vanadium	0 / 6	NA	NA	NA	NA	
Zinc	0 / 6	NA	NA	NA	NA	

NA = not applicable

a Tier 1 evaluation per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing 50% or more nondetects.

the use of several simultaneous tests is recommended for a valid and complete comparison of site versus background distributions (U.S. Environmental Protection Agency [EPA], 1989, 1992, and 1994; U.S. Navy, 2002).

Analytes that fail the Tier 1 and Tier 2 comparisons are subject to a geochemical evaluation to determine if the elevated concentrations are due to natural processes or if they represent potential contamination.

2.1.1 Tier 1

In this step of the background screening process, the MDC of the site data set is compared to the background screening value of two times the background mean (SAIC, 1998). Elements for which the site MDC does not exceed the background screening value are considered to be present at background concentrations, and are not considered site-related chemicals. Elements for which the site MDC exceeds the background screening value undergo further evaluation (Tier 2).

2.1.2 Tier 2

Slippage Test. The nonparametric Slippage test is designed to detect a difference between the upper tails of two distributions, and has been recommended for use in site-to-background comparisons to identify potential localized, or hot-spot, contamination (U.S. Navy, 2002). The test is performed by counting the number (K) of detected concentrations in the site data set that exceed the maximum background measurement, and then comparing this number to a critical value (K_c), which is a function of the number of background samples and the number of site samples. If $K > K_c$, then potential contamination is indicated and the analyte will be subjected to geochemical evaluation. If $K \leq K_c$, then localized contamination is not suspected.

Critical values tables for site and background data sets up to size $n = 50$ are provided in U.S. Navy (2002). Critical values for larger data sets are calculated using the test statistic provided in Rosenbaum (1954). In this report, the Slippage test is performed at the 95 percent confidence level. The test cannot be performed if the maximum background value is a nondetect, because the actual concentration in that sample is unknown.

Wilcoxon Rank Sum Test. The nonparametric WRS test is designed to detect a difference between the medians of two data sets, and has been recommended for use in site-to-background comparisons to identify slight but pervasive contamination (EPA, 2000; U.S. Navy, 2002). In this report, the WRS test is performed when the site and background data sets each contain less

than 50 percent nondetects (i.e., measurements reported as not detected below the laboratory reporting limit). The WRS test will not be performed on data sets containing 50 percent or more nondetects. The medians of such data sets are unknown, and hence the test results would lack sufficient power to yield reliable results.

The WRS test compares two data sets of size n and m ($n > m$), and tests the null hypothesis that the samples were drawn from populations with distributions having the same medians. To perform the test, the two sets of observations are pooled and arranged in order from smallest to largest. Each observation is assigned a rank; that is, the smallest is ranked 1, the next largest is ranked 2, and so on up to the largest observation, which is ranked $(n + m)$. If ties occur between or within samples, each one is assigned the mid-rank. Next, the sum of the ranks of smaller data set m is calculated. Then the test statistic Z is determined,

$$Z = \frac{W - m(m + n + 1)/2}{\sqrt{mn(m + n + 1)/12}}$$

Where:

- W = Sum of the ranks of the smaller data set
- m = Number of data points in smaller group
- n = Number of data points in larger group.

This test statistic Z is used to find the two-sided significance. For instance, if the test statistic yields a probability of a Type I error (p-level) less than 0.2, then there is a statistically significant difference between the medians at the 80 percent confidence level. A Type I error involves rejecting the null hypothesis when it is true. If the p-level is greater than 0.2, then there is no reasonable justification to reject the null hypothesis at the 80 percent confidence level. It can therefore be concluded that the medians of the two data sets are similar, and it can be assumed to be drawn from the same population.

If the p-level is less than 0.2, then the medians of the two distributions are significantly different at the 80 percent confidence level. This can occur if the site data are shifted higher or lower than the background data. If the site data are shifted higher relative to background, then contamination may be indicated, and the analyte in question will be carried on for geochemical evaluation; however, if the site data are shifted lower relative to background, then contamination is not indicated. If the p-level is greater than 0.2, then pervasive site contamination is not suspected.

Box Plots. A quick, robust graphical method recommended by the EPA to visualize and compare two or more groups of data is the box plot comparison (EPA, 1989 and 1992). These plots provide a summary view of the entire data set, including the overall location and degree of symmetry. The box encloses the central 50 percent of the data points so that the top of the box represents the 75th percentile and the bottom of the box represents the 25th percentile. The small box within the larger box represents the median of the data set. The upper whisker extends outward from the box to the maximum point and the lower whisker extends to the minimum point. Nondetect results are set equal to one-half of the reporting limit for plotting purposes.

For each analyte, box plots of site and background data are placed side by side to visually compare the distributions and qualitatively determine whether the data sets are similar or distinct. Accordingly, the box plots are a necessary adjunct to the WRS test. As described previously, the WRS test may indicate that the medians of the site and background data sets are significantly different. Examination of the box plots will confirm whether that difference is caused by site data that are shifted higher or lower relative to background.

Hot Measurement Test. The hot measurement test consists of comparing each site measurement with a concentration value that is representative of the upper limit of the background distribution (EPA, 1994). Ideally, a site sample with a concentration above the background screening value would have a low probability of being a member of the background distribution, and may be an indicator of contamination. It is important to select such a background screening value carefully so that the probability of falsely identifying site samples as contaminated or uncontaminated is minimized.

The 95th upper tolerance limit (95th UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95th percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, and 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect. To perform the test, each analyte's site MDC is compared to the background 95th UTL or 95th percentile, in accordance with the type of background distribution. If the site MDC exceeds the background screening value, then that analyte will undergo a geochemical evaluation. If the MDC does not exceed the background threshold value, then hot-spot contamination is not indicated.

2.1.3 Geochemical Evaluation

If an analyte fails either of the statistical tests described above, then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The methodology and results of the geochemical evaluation are provided in Appendix H.

3.0 Results of the Site-to-Background Comparisons

This section presents the results of the site-to-background comparisons for 23 TAL metals in the Range 23A surface soil, subsurface soil, groundwater, sediment, and surface water samples. Tables 1 through 5 summarize the Tier 1 and Tier 2 test results for each media as discussed in the following sections. Statistical test results are discussed in detail below. Box plots are also discussed below and are provided in Attachment 1.

3.1 Surface Soil

Twenty-three TAL metals were evaluated in the Range 23A surface soil. Three metals (antimony, cadmium, and thallium) had no detected concentrations in surface soil. No further discussion of these metals is included.

Twelve metals (aluminum, barium, beryllium, calcium, chromium, cobalt, iron, lead, manganese, mercury, sodium, and vanadium) had no detected concentrations above their respective background screening values, passing the Tier 1 evaluation. These metals are considered within the range of background and will not be tested or discussed any further.

The remaining eight metals underwent Tier 2 evaluation. The statistical test results and box plots are discussed in detail below.

Table 1 summarizes the Tier 1 and Tier 2 test results for surface soil.

Arsenic

Tier 1 Evaluation

Four site samples exceed the background screening value of 13.73 milligrams per kilogram (mg/kg).

Slippage Test

The critical value, K_c , for arsenic is 2. Arsenic has no site samples exceeding the maximum background measurement ($K=0$). Because $K < K_c$, arsenic passes the Slippage test.

WRS Test

The WRS test $p\text{-level} < 0.001$ indicates a significant difference between the site and background distributions.

Box Plot

Box plots for the site and background data sets are provided in Figure 1-1. The site minimum and interquartile range are higher than the corresponding background values. The site maximum is less than that of background.

Conclusion

Because arsenic in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation

One site sample exceeds the background screening value of 12.71 mg/kg.

Slippage Test

K_c for copper is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, copper passes the Slippage test.

WRS Test

The $p\text{-level}$ of 0.0018 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-1). The site maximum is less than that of background.

Conclusion

Because copper in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Magnesium

Tier 1 Evaluation

One site sample exceeds the background screening value of 1,033 mg/kg.

Slippage Test

K_c for magnesium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, magnesium passes the Slippage test.

WRS Test

The $p\text{-level} < 0.001$ indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-2). The site maximum is lower compared to that of background.

Conclusion

Because magnesium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation

One site sample exceeds the background screening value of 10.33 mg/kg.

Slippage Test

K_c for nickel is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

No WRS test was performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site 25th percentile, median, 75th percentile and maximum are lower than the corresponding background values (Figure 1-2). The site minimum is higher than that of background. The shape and location of the site box plot are influenced by the high percentage of nondetects (64 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of nickel is less than the background 95th percentile of 19.96 mg/kg.

Conclusion

Nickel in surface soil passed the Tier 2 evaluation and is considered to be within the range of background.

Potassium

Tier 1 Evaluation

One site sample exceeds the background screening value of 799.76 mg/kg.

Slippage Test

K_c for potassium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, potassium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-3), and the site maximum is less than that of background.

Conclusion

Because potassium in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation

Four site samples exceed the background screening value of 0.48 mg/kg.

Slippage Test

K_c for selenium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, selenium passes the Slippage test.

WRS Test

No WRS test was performed because the site and background data sets contain more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-3), and the site maximum is less than that of background. The shape and location of the background and site box plots are influenced by the high percentage of nondetects (99 percent and 64 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.563 mg/kg.

Conclusion

Because selenium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation

Six site samples exceed the background screening value of 0.36 mg/kg.

Slippage Test

K_c for silver is 2, and one site sample exceeds the maximum background measurement. Because $K < K_c$, silver passes the Slippage test.

WRS Test

The p -level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-4), and the site maximum is similar to that of background.

Hot Measurement Test

The site MDC of silver exceeds the background 95th percentile of 0.774 mg/kg.

Conclusion

Because silver in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation

One site sample exceeds the background screening value of 40.64 mg/kg.

Slippage Test

K_c for zinc is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, zinc passes the Slippage test.

WRS Test

The p-level of 0.003 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-4). The site maximum is lower than that of background.

Conclusion

Because zinc in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.2 Subsurface Soil

Twenty-three TAL metals were evaluated in Range 23A, subsurface soil. One metal, antimony, had no detected concentrations in the subsurface soil samples. No further discussion of this metal is included.

Five metals (calcium, chromium, iron, sodium, and vanadium) had no detected concentrations above the background screening values, passing the Tier 1 evaluation. These metals are considered within the range of background and no further testing or discussion of these metals is included.

The remaining 17 metals underwent Tier 2 evaluation. The statistical tests and box plots are discussed in detail below.

Table 2 summarizes the Tier 1 and Tier 2 test results for subsurface soil.

Aluminum

Tier 1 Evaluation

Three site samples exceed the background screening value of 13,591 mg/kg.

Slippage Test

The critical value, K_c , for aluminum is 2. No site samples exceed the maximum background measurement. Because $K < K_c$, aluminum passes the Slippage test.

WRS Test

The p-level of 0.41 indicates a good agreement between the site and background distributions.

Box Plot

The site 25th percentile, median, and maximum are similar to the corresponding background values (Figure 1-5). The site minimum and 75th percentile are higher than that of background.

Conclusion

Aluminum in subsurface soil passes the Tier 2 evaluation and is considered to be within the range of background.

Arsenic

Tier 1 Evaluation

Four site samples exceed the background screening value of 18.3 mg/kg.

Slippage Test

K_c for arsenic is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, arsenic passes the Slippage test.

WRS Test

The p-level of 0.006 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The site maximum is less than that of background.

Conclusion

Because arsenic in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation

One site sample exceeds the background screening value of 233.62 mg/kg.

Slippage Test

K_c for barium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, barium passes the Slippage test.

WRS Test

The p-level of 0.475 indicates a significant difference between the site and background distributions.

Box Plot

The site and background medians are similar (Figure 1-6). The site minimum, 25th percentile, 75th percentile, and maximum are lower than the corresponding background values.

Conclusion

Barium in subsurface soil is considered to be within the range of background.

Beryllium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.86 mg/kg.

Slippage Test

K_c for beryllium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, beryllium passes the Slippage test.

WRS Test

No WRS test was performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-6), and the site maximum is lower than that of background. The shape and location of the site box plot are influenced by the high percentage of nondetects (73 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of beryllium is less than the background 95th UTL of 2.19 mg/kg.

Conclusion

Because beryllium in subsurface soil passed the Tier 2 evaluation, it is considered to be within the range of background.

Cadmium

Tier 1 Evaluation

Two site samples exceed the background screening value of 0.22 mg/kg.

Slippage Test

K_c for cadmium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, cadmium passes the Slippage test.

WRS Test

No WRS test was performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-7), and the site maximum is slightly lower than that of background. The shape and location of the site box plot are influenced by the high percentage of nondetects (82 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of cadmium exceeds the background 95th percentile of 0.62 mg/kg.

Conclusion

Because cadmium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation

One site sample exceeds the background screening value of 17.54 mg/kg.

Slippage Test

K_c for cobalt is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, cobalt passes the Slippage test.

WRS Test

The p-level of 0.21 indicates a good agreement between the site and background distributions.

Box Plot

The site 25th percentile, median, and 75th percentile are slightly higher than that of background (Figure 1-7). The site maximum is lower than that of background, and the site minimum appears significantly higher than the corresponding background value.

Conclusion

Cobalt in subsurface soil is considered to be within the range of background.

Copper

Tier 1 Evaluation

Four site samples exceed the background screening value of 19.43 mg/kg.

Slippage Test

K_c for copper is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, copper passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-8). The site maximum is lower than that of background.

Conclusion

Because copper in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation

One site sample exceeds the background screening value of 38.53 mg/kg.

Slippage Test

K_c for lead is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, lead passes the Slippage test.

WRS Test

The p-level of 0.49 indicates a good agreement between the site and background distributions.

Box Plot

The site and background medians appear to be the same (Figure 1-8). The site minimum and interquartile range are higher than the corresponding background values, and the site maximum is lower than that of background.

Conclusion

Lead in subsurface soil is considered to be within the range of background.

Magnesium

Tier 1 Evaluation

One site sample exceeds the background screening value of 766.24 mg/kg.

Slippage Test

K_c for magnesium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, magnesium passes the Slippage test.

WRS Test

The p-level of 0.002 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-9). The site maximum is less than that of background.

Conclusion

Because magnesium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation

Two site samples exceed the background screening value of 1,355 mg/kg.

Slippage Test

K_c for manganese is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The p-level of 0.91 indicates excellent agreement between the site and background distributions.

Box Plot

The site 25th percentile, median, and maximum are slightly lower than the corresponding background values (Figure 1-9). The site minimum and 75th percentile are higher than that of background.

Conclusion

Manganese in subsurface soil passed the Tier 2 evaluation and is considered to be within the range of background.

Mercury

Tier 1 Evaluation

Three site samples exceed the background screening value of 0.07 mg/kg.

Slippage Test

K_c for mercury is 2, and one site sample exceeds the maximum background measurement. Because $K < K_c$, mercury passes the Slippage test.

WRS Test

The WRS test was not performed because the background and site data sets have more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10). The site and background maximums are similar. The shape and location of the background and site box plots are influenced by the percentage of nondetects (53 percent and 55 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.094 mg/kg.

Conclusion

Because mercury in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation

Two site samples exceed the background screening value of 12.89 mg/kg.

Slippage Test

K_c for nickel is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

The p-level of 0.39 indicates good agreement between the site and background distributions.

Box Plot

The site minimum, median, and 75th percentile are higher than the corresponding background values (Figure 1-10). The site 25th percentile and maximum are lower than that of background.

Conclusion

Because nickel passed the Tier 2 evaluation, it is considered to be within the range of background.

Potassium

Tier 1 Evaluation

Two site samples exceed the background screening value of 710.74 mg/kg.

Slippage Test

K_c for potassium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, potassium passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-11). The site maximum is less than that of background.

Conclusion

Because potassium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.47 mg/kg.

Slippage Test

Because the maximum background result for selenium is a nondetect, the Slippage test cannot be done.

WRS Test

The WRS test was not performed because the background and site data sets contain more than 50 percent nondetect.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-11). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (98 percent and 91 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.574 mg/kg.

Conclusion

Because selenium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation

Six site samples exceed the background screening value of 0.24 mg/kg.

Slippage Test

Because the maximum background result of silver is a nondetect, the Slippage test cannot be done.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-12).

Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.88 mg/kg.

Conclusion

Because silver in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Thallium

Tier 1 Evaluation

One site sample exceeds the background screening value of 1.4 mg/kg.

Slippage Test

The K_c of thallium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, thallium passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-12). The site maximum is lower than that of background. The shape and location of the site box plot are influenced by the high percentage of nondetects (91 percent), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC is less than the background 95th percentile of 6.62 mg/kg.

Conclusion

Because thallium in subsurface soil passed Tier 2 evaluation, it is considered to be within the range background.

Zinc

Tier 1 Evaluation

Four site samples exceed the background screening value of 34.86 mg/kg.

Slippage Test

K_c for zinc is 2, and two site samples exceed the maximum background measurement. Because $K \leq K_c$, zinc passes the Slippage test.

WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-13).

Conclusion

Because zinc in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.3 Groundwater

This section presents the results of the site-to-background comparisons for 23 metals in unfiltered groundwater samples.

Six metals (antimony, cadmium, potassium, selenium, silver, and thallium) had no detected results in the site samples and are not discussed any further.

Four metals had no detected concentrations that exceeded their respective background screening values, passing the Tier 1 evaluation. These metals (arsenic, calcium, magnesium, and zinc) are considered to be within the range of background, and will not be included in any further evaluation or discussion.

The remaining metal, selenium, underwent Tier 2 evaluation. The results of the statistical tests are discussed in detail below and summarized in Table 3. Box plots are provided in Attachment 1.

Aluminum

Tier 1 Evaluation

One site sample exceeds the background screening value of 2.335 mg/L.

Slippage Test

The K_c for aluminum is 2 and one site sample exceeds the maximum background measurement. Because $K < K_c$, aluminum passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples.

Box Plot

The site minimum, 25th percentile, 75th percentile, and maximum are higher than the corresponding background values (Figure 1-13). The site median is lower than that of background.

Hot Measurement Test

The site MDC of aluminum exceeds the background 95th percentile of 5.95 mg/L.

Conclusion

Because aluminum in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.127 mg/L.

Slippage Test

The K_c for barium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, barium passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples.

Box Plot

The site 25th percentile, median, and maximum are lower than the corresponding background values (Figure 1-14). The site minimum and 75th percentile are higher than the corresponding background values.

Hot Measurement Test

The site MDC of barium is less than the background 95th UTL of 0.472 mg/L.

Conclusion

Because barium in groundwater passes the Tier 2 evaluation, it is considered to be within the range of background.

Beryllium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.001247 mg/L.

Slippage Test

The maximum background value for beryllium is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-14). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (72 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of beryllium is less than the background 95th percentile of 0.005 mg/L.

Conclusion

Beryllium in groundwater is considered to be within the range of background.

Chromium

Tier 1 Evaluation

No background screening value is available for chromium. One site sample had a detected concentration.

Slippage Test

The maximum background value for chromium is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-15). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of chromium is less than the background 95th percentile of 0.0168 mg/L.

Conclusion

Chromium in groundwater is considered to be within the range of background.

Cobalt

Tier 1 Evaluation

Two site samples exceed the background screening value of 0.02336 mg/L.

Slippage Test

The K_c for cobalt is 2, and 2 site samples exceed the maximum background measurement. Because $K \leq K_c$, cobalt passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain 50 percent or more nondetects.

Box Plot

The site minimum and 25th percentile appear to be the same as the corresponding background values (Figure 1-15). The site median, 75th percentile, and maximum are higher than that of

background. The shape and location of the background and site box plots are influenced by the high percentage of nondetects (94 percent and 50 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of cobalt exceeds than the background 95th percentile of 0.0202 mg/L.

Conclusion

Because cobalt in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.02548 mg/L.

Slippage Test

The K_c for copper is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, copper passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site median is slightly higher than that of background (Figure 1-16). The site minimum, 25th percentile, and 75th percentile are higher than the corresponding background values, and the site maximum is less than that of background. The shape and location of the background and site box plots are influenced by the high percentage of nondetects (82 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of copper is less than the background 95th percentile of 0.207 mg/L.

Conclusion

Copper in groundwater is considered to be within the range of background.

Iron

Tier 1 Evaluation

One site sample exceeds the background screening value of 7.04 mg/L.

Slippage Test

The K_c for iron is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, iron passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples.

Box Plot

The site minimum and interquartile range are slightly higher than the corresponding background values (Figure 1-16). The site maximum is slightly lower than that of background.

Hot Measurement Test

The site MDC of iron is less than the background 95th percentile of 22 mg/L.

Conclusion

Iron in groundwater is considered to be within the range of background.

Lead

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.008 mg/L.

Slippage Test

The maximum background value for lead is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-17). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (60 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of lead is less than the background 95th percentile of 0.0434 mg/L.

Conclusion

Lead in groundwater is considered to be within the range of background.

Manganese

Tier 1 Evaluation

Two site samples exceed the background screening value of 0.5805 mg/L.

Slippage Test

K_c for manganese is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-17). The site maximum is less than that of background.

Hot Measurement Test

The site MDC of manganese is less than the background 95th percentile of 4.134 mg/L.

Conclusion

Manganese in groundwater is considered to be within the range of background.

Mercury

Tier 1 Evaluation

There is no screening value for mercury, and one site sample had a detected concentration.

Slippage Test

The maximum background value for mercury is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-18). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of mercury exceeds the background 95th percentile of 0.000243 mg/L.

Conclusion

Because mercury in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation

No background screening value is available for nickel. Two samples had detected results.

Slippage Test

The maximum background value for nickel is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain 50 percent or more nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-18). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 50 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of nickel exceeds the background 95th percentile of 0.0343 mg/L.

Conclusion

Because nickel in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Sodium

Tier 1 Evaluation

One site sample exceeds the background screening value of 14.846 mg/L.

Slippage Test

The K_c for sodium is 2, and no site samples exceed the maximum background measurement for sodium. Because $K < K_c$, sodium passes the Slippage test.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples.

Box Plot

The site 25th percentile, median, and maximum are lower than the corresponding background values (Figure 1-19). The site minimum is slightly higher than that of background and the site 75th percentile is higher than the corresponding background value.

Hot Measurement Test

The site MDC of sodium is less than the background 95th UTL of 49.028 mg/L.

Conclusion

Sodium in groundwater is considered to be within the range of background.

Vanadium

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.017 mg/L.

Slippage Test

The maximum background value for vanadium is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the site data set contains less than 5 samples. In addition, the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-19). The shape and location of the background and site box plots are influenced by the high percentage of nondetects (96 percent and 75 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of vanadium is less than the background 95th percentile of 0.0276 mg/L.

Conclusion

Vanadium in groundwater is considered to be within the range of background.

3.4 Sediment

This section presents the results of the site-to-background comparisons for 23 TAL metals for the Range 23A sediment samples. Four metals (antimony, cadmium, silver, and thallium) had no detected concentrations in sediment. No further discussion of these elements is included.

Fifteen metals (arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, magnesium, mercury, nickel, potassium, sodium, vanadium, and zinc) had no site samples exceeding their respective background screening values. Because these metals passed the Tier 1 evaluation, they are considered to be within the range of background and will not be tested or discussed any further.

The remaining four metals (aluminum, calcium, manganese, and selenium) underwent Tier 2 evaluation. The results are discussed in detail below. Table 4 summarizes the Tier 1 and Tier 2 results for sediment.

Aluminum

Tier 1 Evaluation

Three site samples exceed the background screening value of 8,593 mg/kg.

Slippage Test

The critical value, K_c , for aluminum is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, aluminum passes the Slippage test.

WRS Test

The p-level of 0.004 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-20). The site maximum is lower to that of background.

Conclusion

Because aluminum in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Calcium

Tier 1 Evaluation

One site sample exceeds the background screening value of 1,111.5 mg/kg.

Slippage Test

K_c for calcium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, calcium passes the Slippage test.

WRS Test

The p-level of 0.239 indicates a good agreement between the site and background distributions.

Box Plot

The site interquartile range and maximum are lower than the corresponding background values (Figure 1-20). The site minimum is higher than that of background.

Conclusion

Calcium in sediment passed the Tier 2 evaluation and is considered to be within the range of background.

Manganese

Tier 1 Evaluation

One site sample exceeds the background screening value of 712.31 mg/kg.

Slippage Test

K_c for manganese is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, manganese passes the Slippage test.

WRS Test

The p-level of 0.53 indicates a strong agreement between the site and background distributions.

Box Plot

The site minimum and median are higher than the corresponding background values (Figure 1-21). The site 25th percentile and maximum are lower to that of background, and the site 75th percentile appears to be the same as background.

Conclusion

Manganese in sediment is considered to be within the range of background.

Selenium

Tier 1 Evaluation

Two site samples exceed the background screening value of 0.72 mg/kg.

Slippage Test

The critical value, K_c , for selenium is 2, and no site samples exceed the maximum background measurement. Because $K < K_c$, selenium passes the Slippage test.

WRS Test

No WRS test was performed because the background and site data sets contain 50 percent or more nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-21). The site maximum is less than that of background. The shape and location of the background and site box plot are influenced by the high percentage of nondetects (93 percent and 50 percent, respectively) and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC of selenium is less than the background 95th percentile of 1.03 mg/kg.

Conclusion

Selenium in sediment passed the Tier 2 evaluation and is considered to be within the range of background.

3.5 Surface Water

This section presents the results of the site-to-background comparisons for the 23 metals tested in surface water samples from Range 23A. Thirteen metals (antimony, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc) had no detected concentrations in the site samples and are not discussed any further.

Eight metals (aluminum, barium, calcium, iron, magnesium, manganese, potassium, and sodium) had no detected concentrations exceeding their respective background screening values. These metals are considered within the range of background based on the Tier 1 evaluation, and will not be tested or discussed further.

The remaining two metals (arsenic and cobalt) underwent Tier 2 evaluation. The results of these tests are discussed in detail below. Box plots are provided in Attachment 1.

Arsenic

Tier 1 Evaluation

One site sample exceeds the background screening value of 0.00217 mg/L.

Slippage Test

The critical value, K_c , for arsenic is 2. No site samples exceed the maximum background measurement. Because $K < K_c$, arsenic passes the Slippage test.

WRS Test

The WRS test was not performed because the background and site data sets contain more than 50 percent nondetects.

Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-22). The site maximum is less than that of background. The shape and location of the background and site box plot are influenced by the high percentage of nondetects (86 percent and 67 percent, respectively) and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC for arsenic exceeds than the background 95th percentile of 0.0034 mg/L.

Conclusion

Because arsenic in surface water failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation

No background screening value is available for cobalt. Three site samples have detected results.

Slippage Test

The maximum background value for cobalt is a nondetect, so the Slippage test was not performed.

WRS Test

The WRS test was not performed because the background and site data sets contain 50 percent of more nondetects.

Box Plot

The site minimum and 25th percentile appear to be the same as the corresponding background values (Figure 1-22). The site median is slightly higher than that of background, and the site 75th percentile and maximum are higher than the corresponding background values. The shape and location of the background and site box plot are influenced by the high percentage of nondetects (100 percent and 50 percent, respectively), and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test

The site MDC for cobalt is less than the background 95th percentile of 0.025 mg/L.

Conclusion

Cobalt in surface water passes the Tier 2 evaluation and is considered to be within the range of background.

4.0 Summary and Conclusions

The statistical methodology used to compare site data from Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X, and the background data for 23 elements in surface soil, subsurface soil, groundwater, sediment, and surface water includes a comparison of the site MDC to the background screening value (Tier 1 evaluation). Analytes that failed this comparison were subjected to the Slippage test and Wilcoxon rank sum test. Box-and-whisker plots were prepared to visually compare the two data sets and properly interpret the WRS test results. If the Slippage test and/or the WRS test could not be performed, the Hot Measurement test was included as part of the Tier 2 statistical evaluation. Analytes that underwent Tier 2 evaluation and failed any component of the statistical site-to-background comparison are carried forward for Tier 3 geochemical evaluation to determine if natural processes can explain the elevated concentrations.

Tables 1 through 5 summarize the comparison test results and the metals carried forward for geochemical evaluation.

5.0 References

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ATTACHMENT 1

Figure 1-1

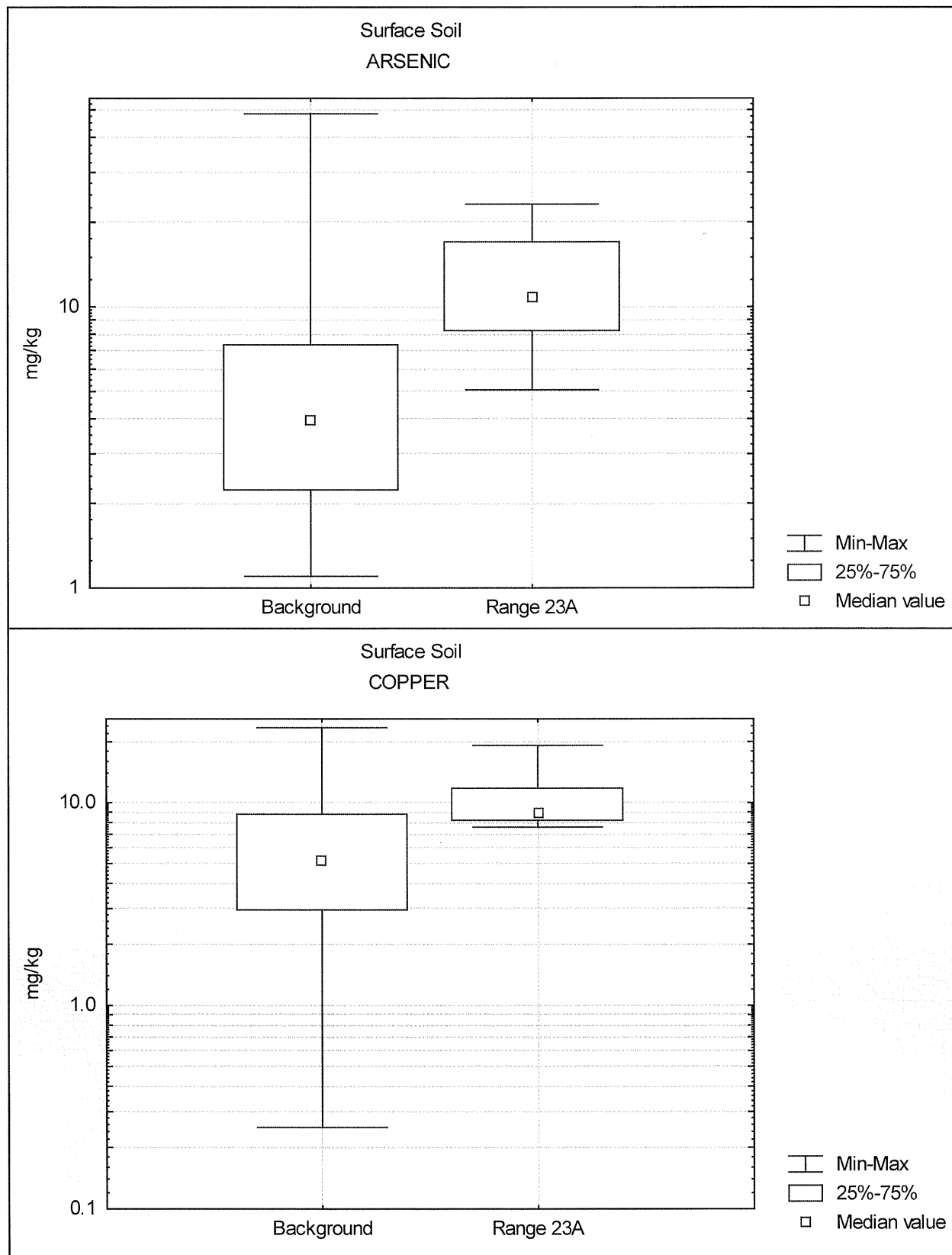


Figure 1-2

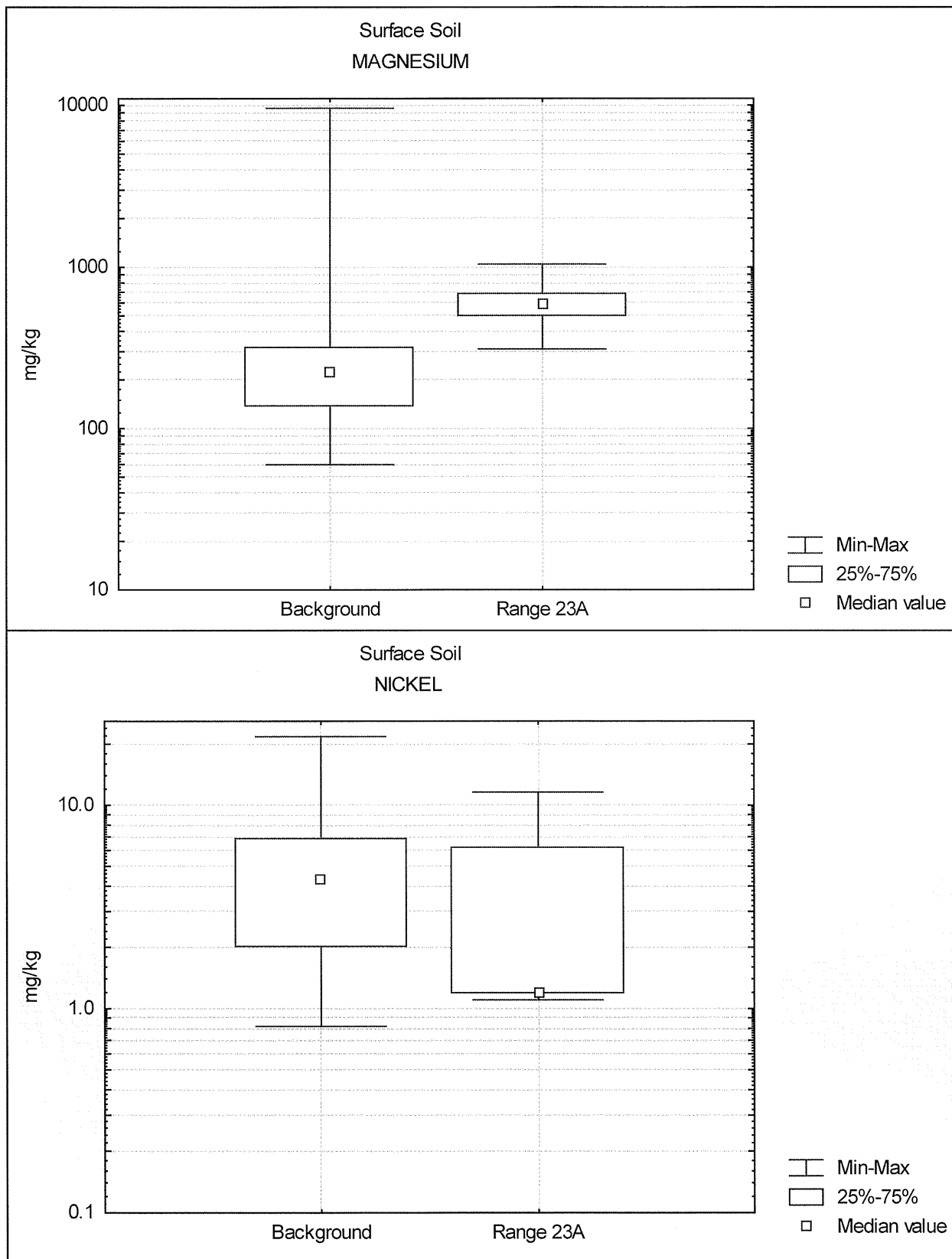


Figure 1-3

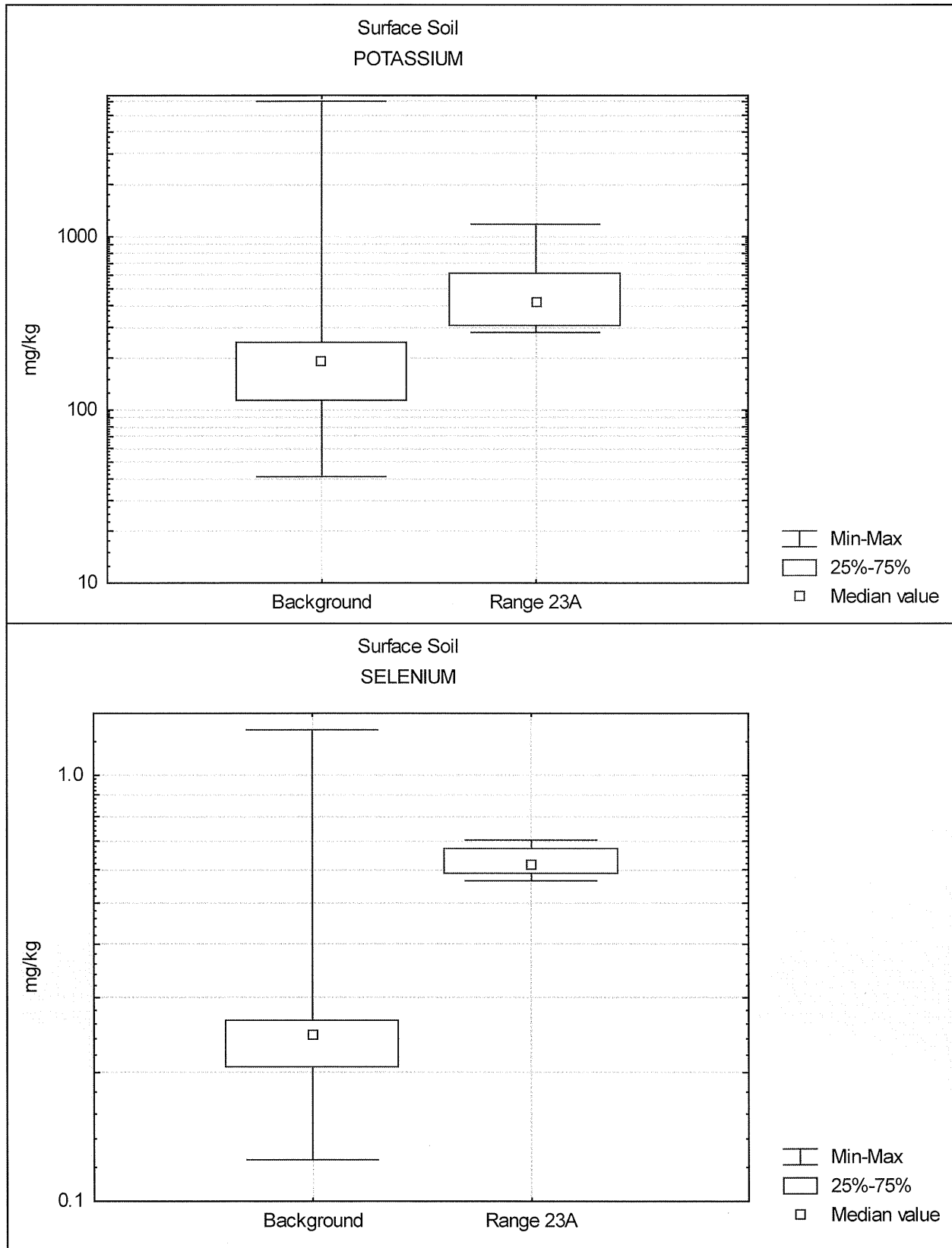


Figure 1-4

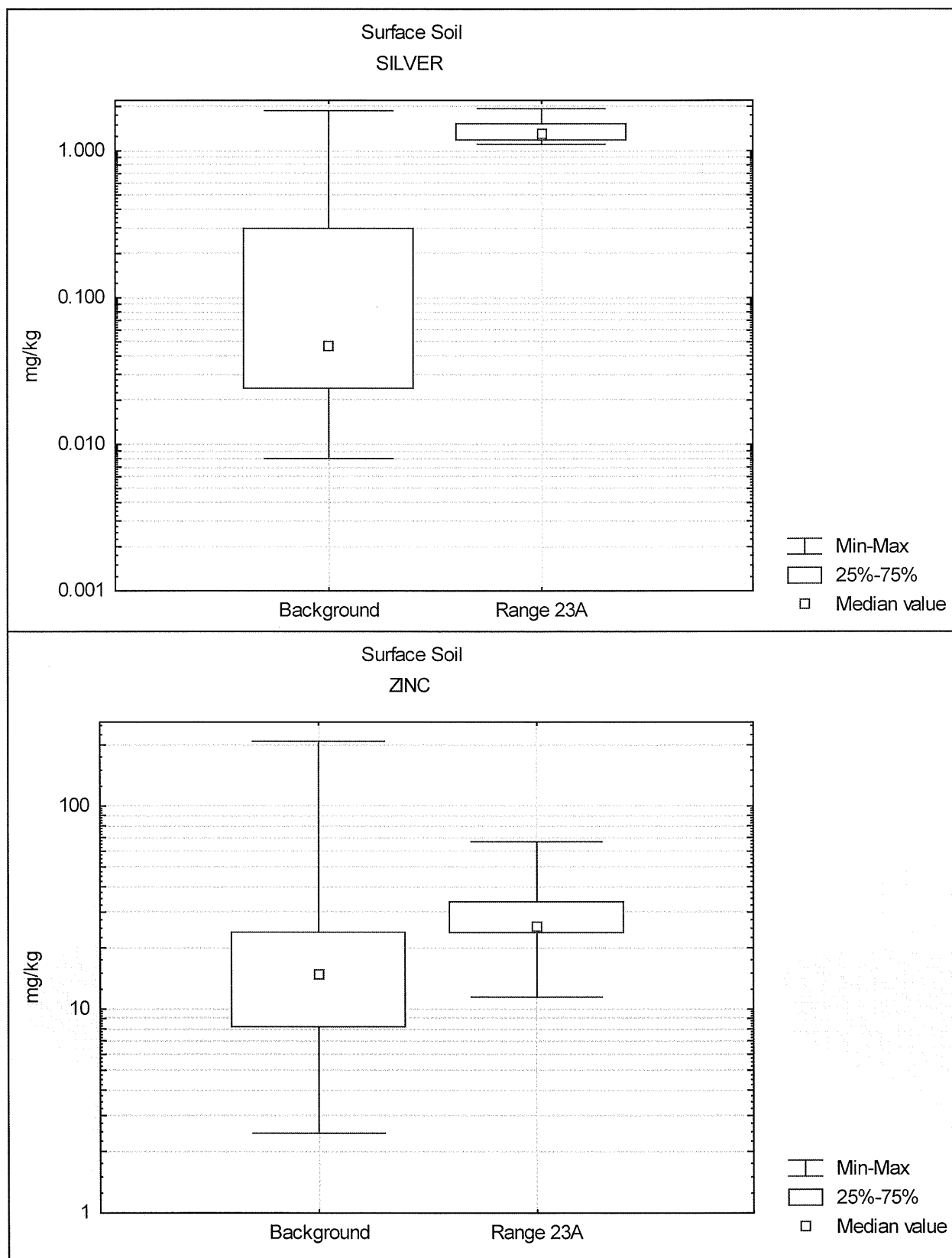


Figure 1-5

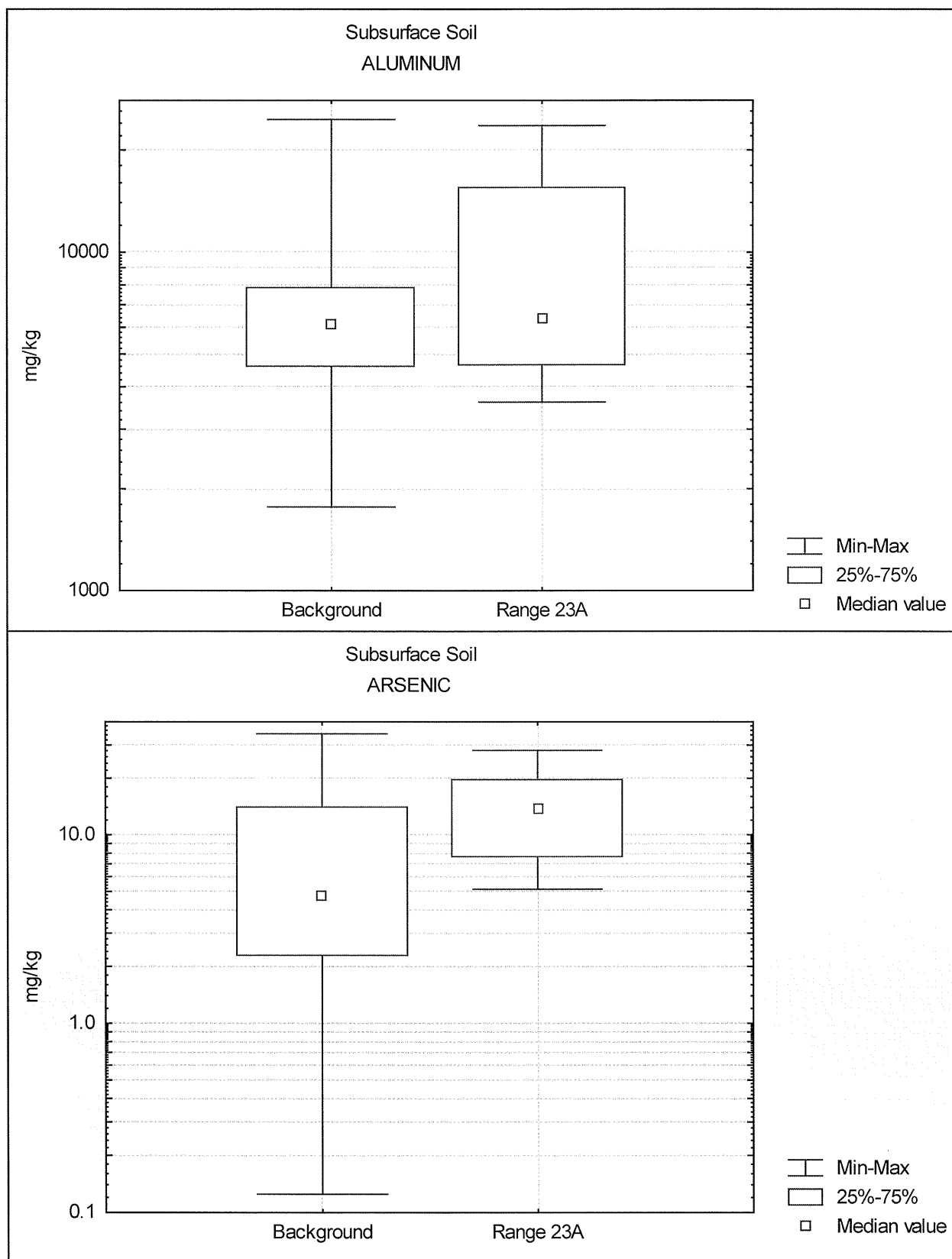


Figure 1-6

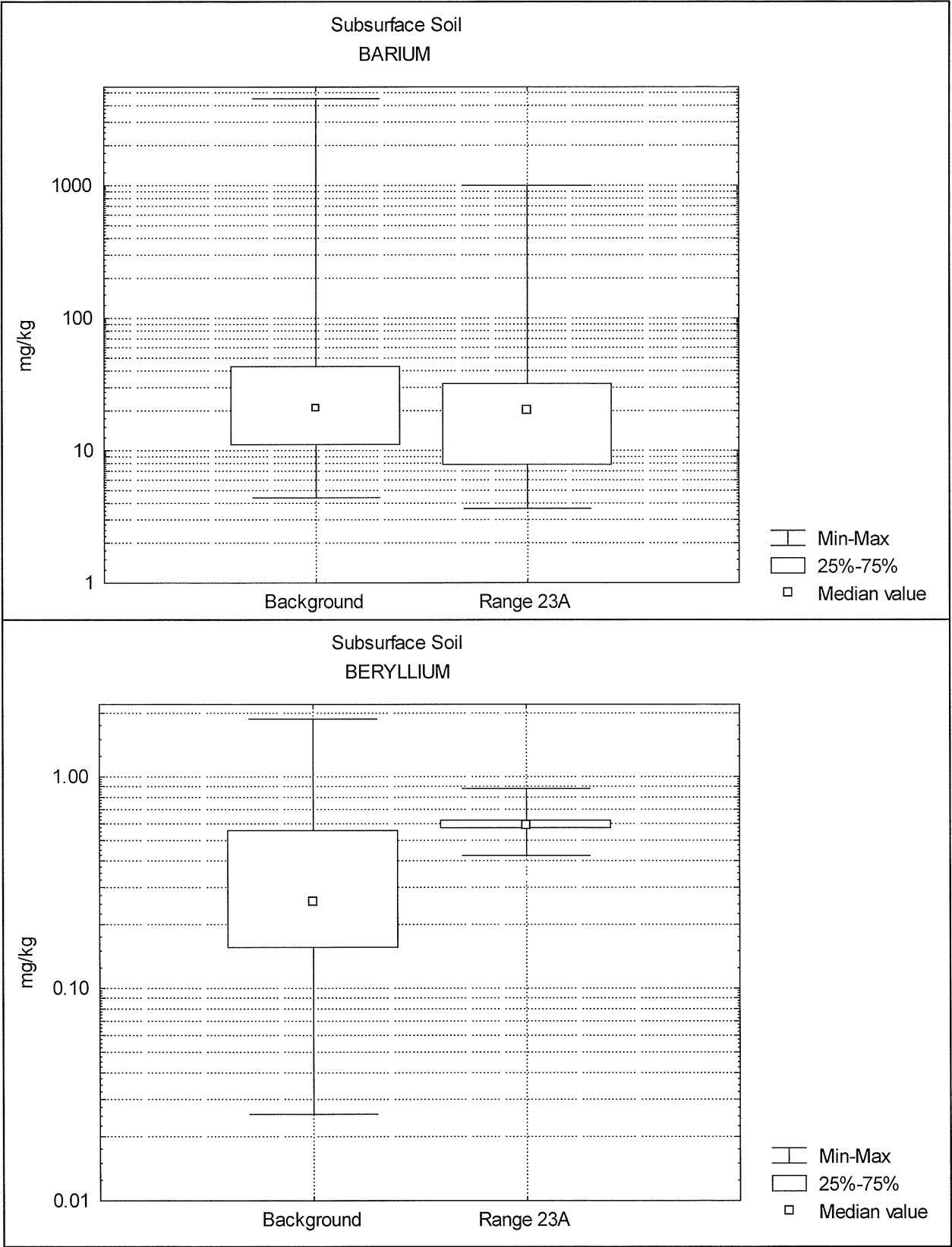


Figure 1-7

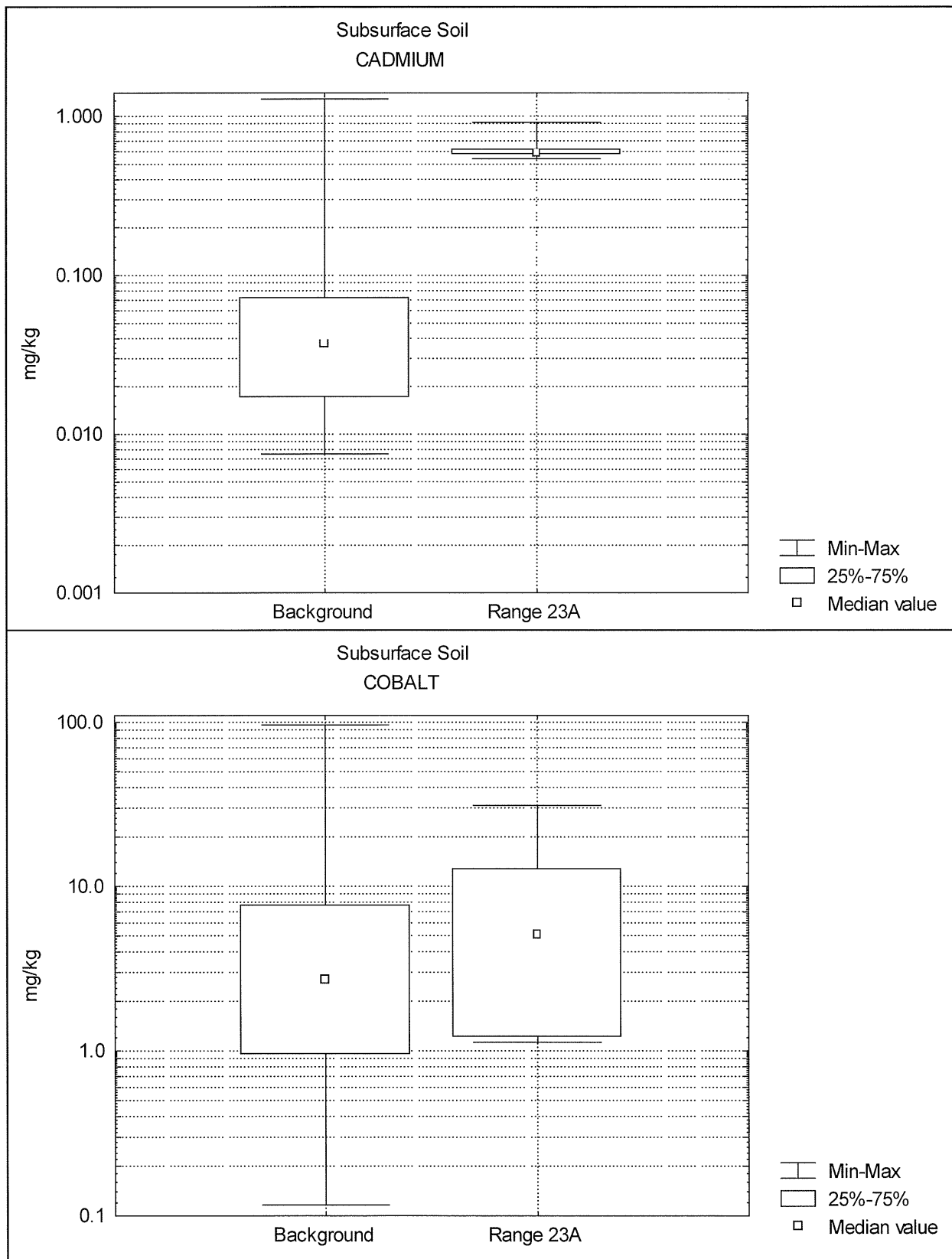


Figure 1-8

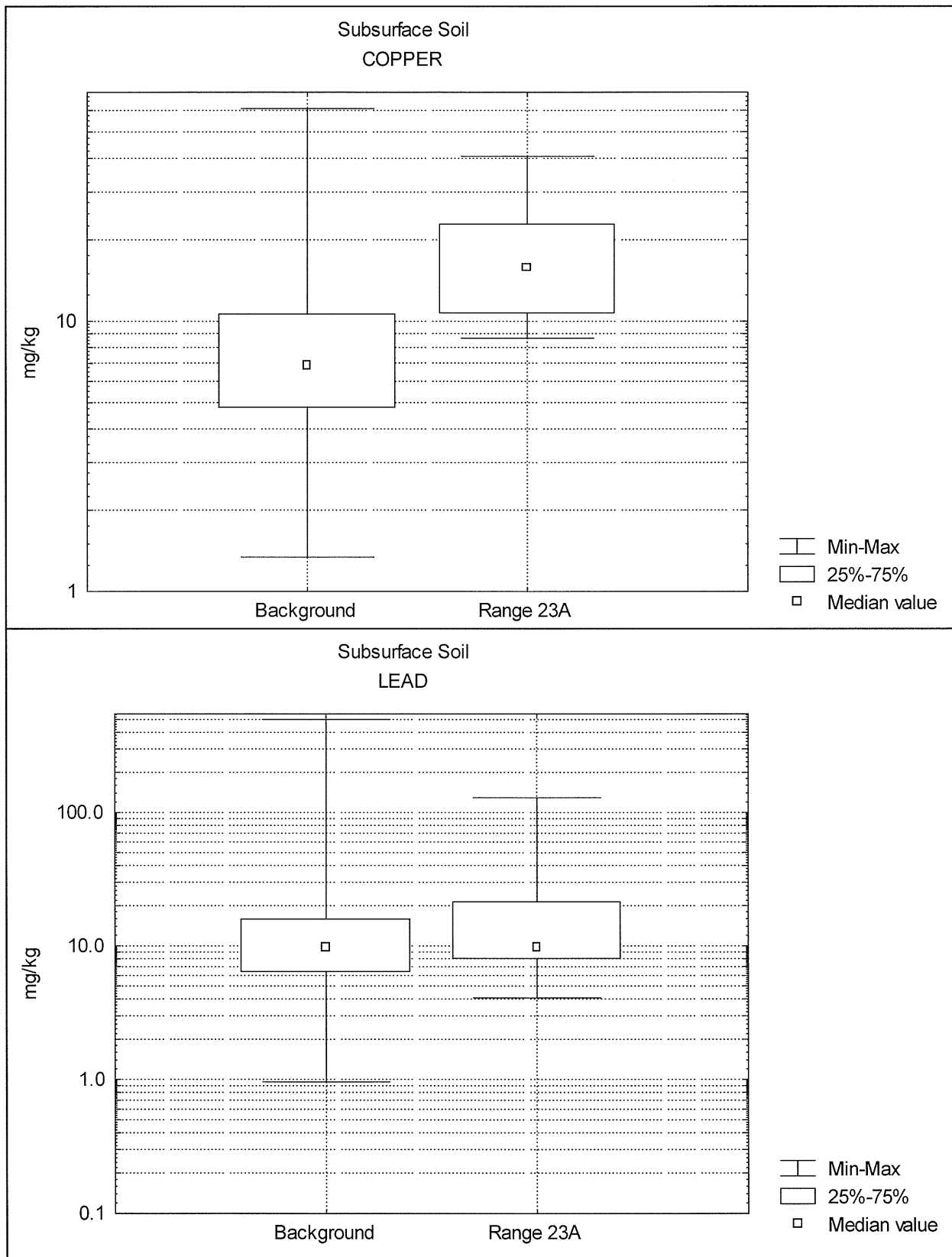


Figure 1-9

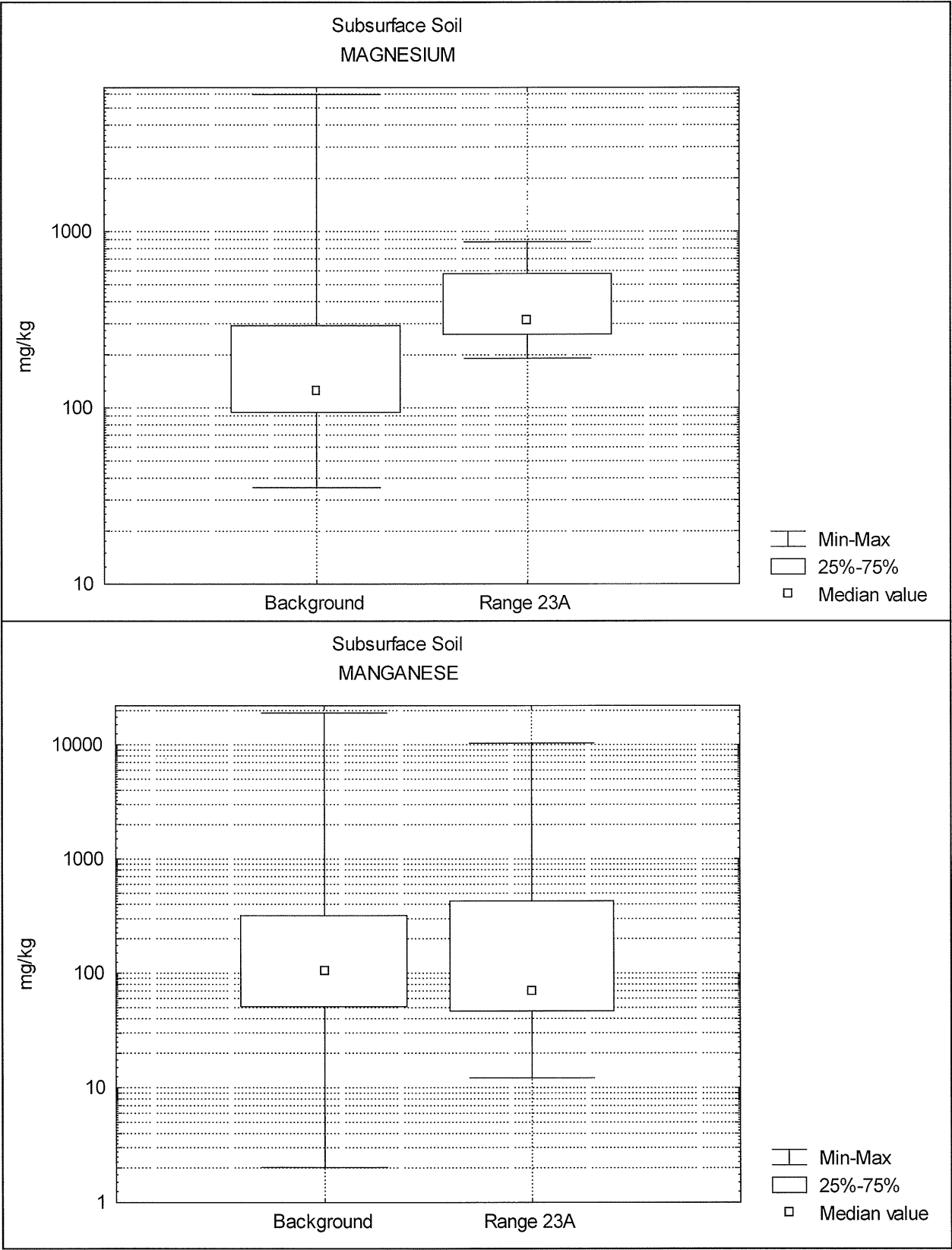


Figure 1-10

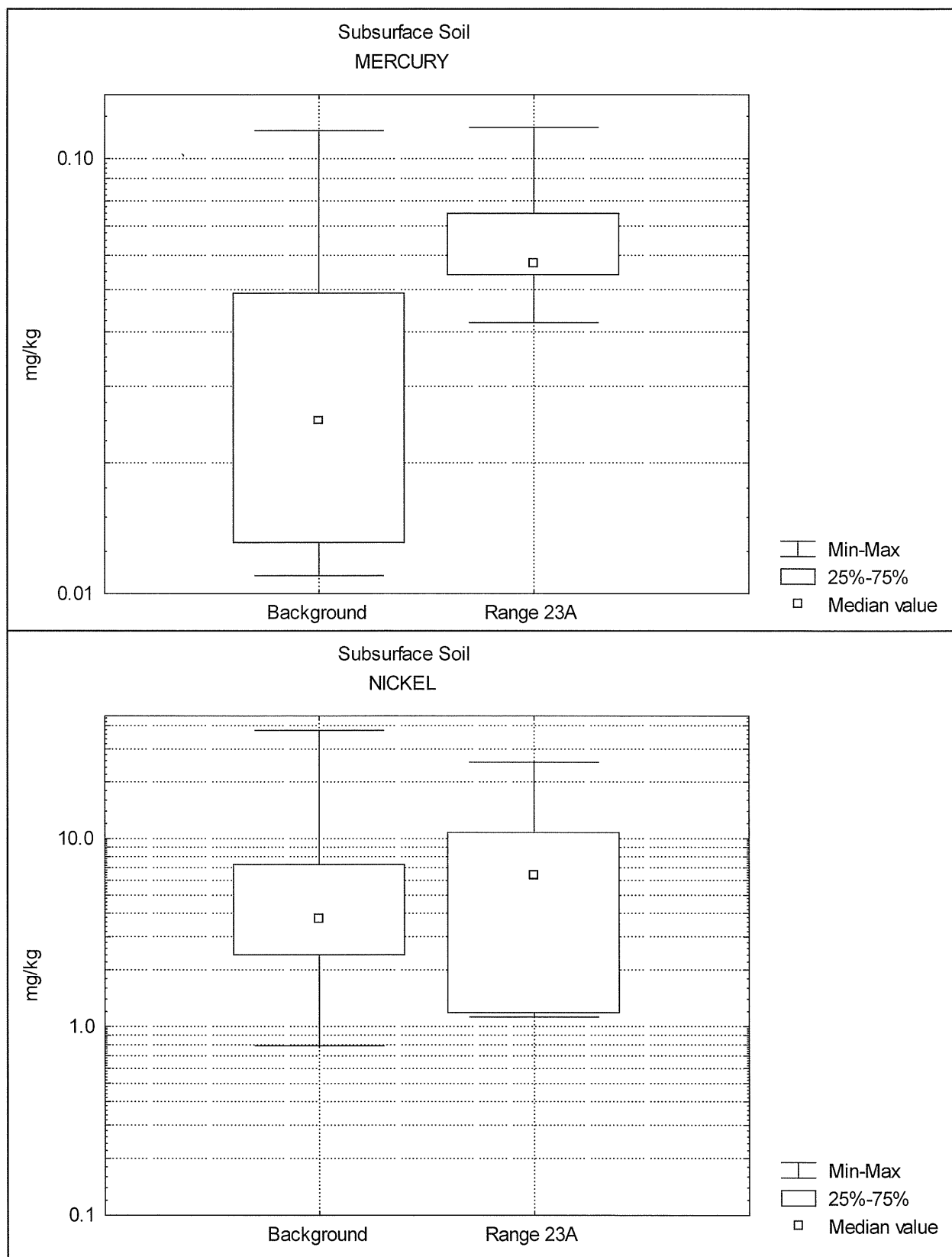


Figure 1-11

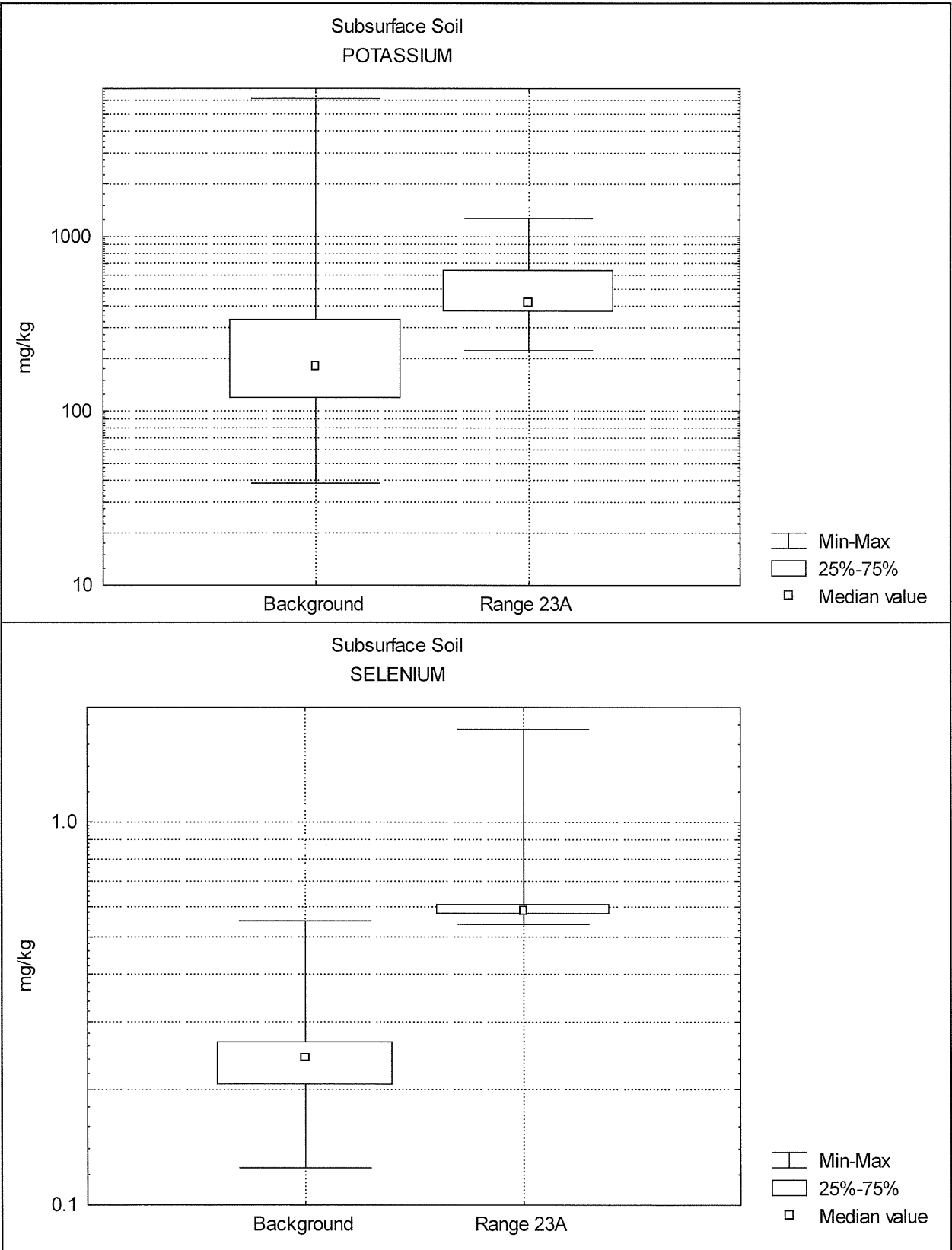


Figure 1-12

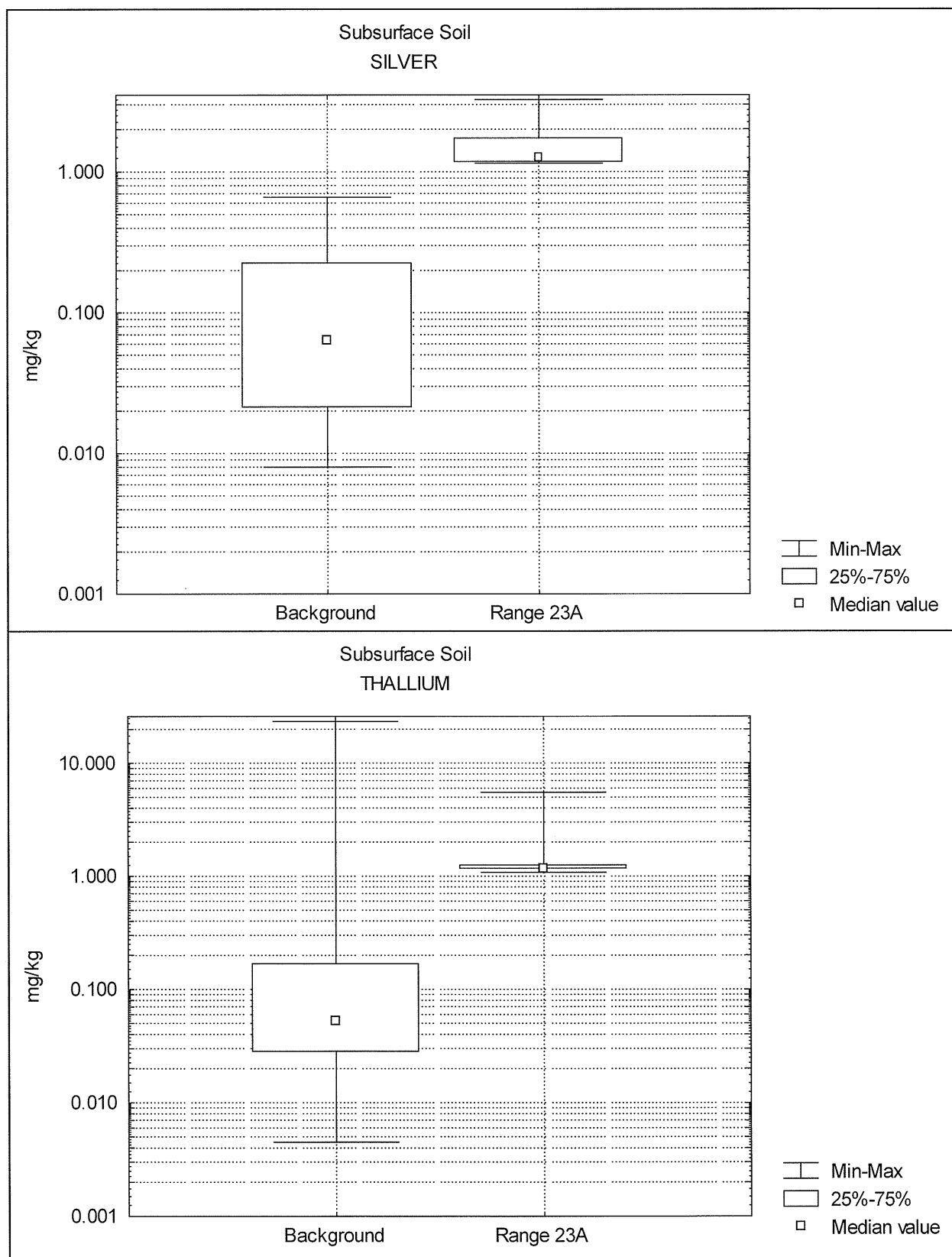


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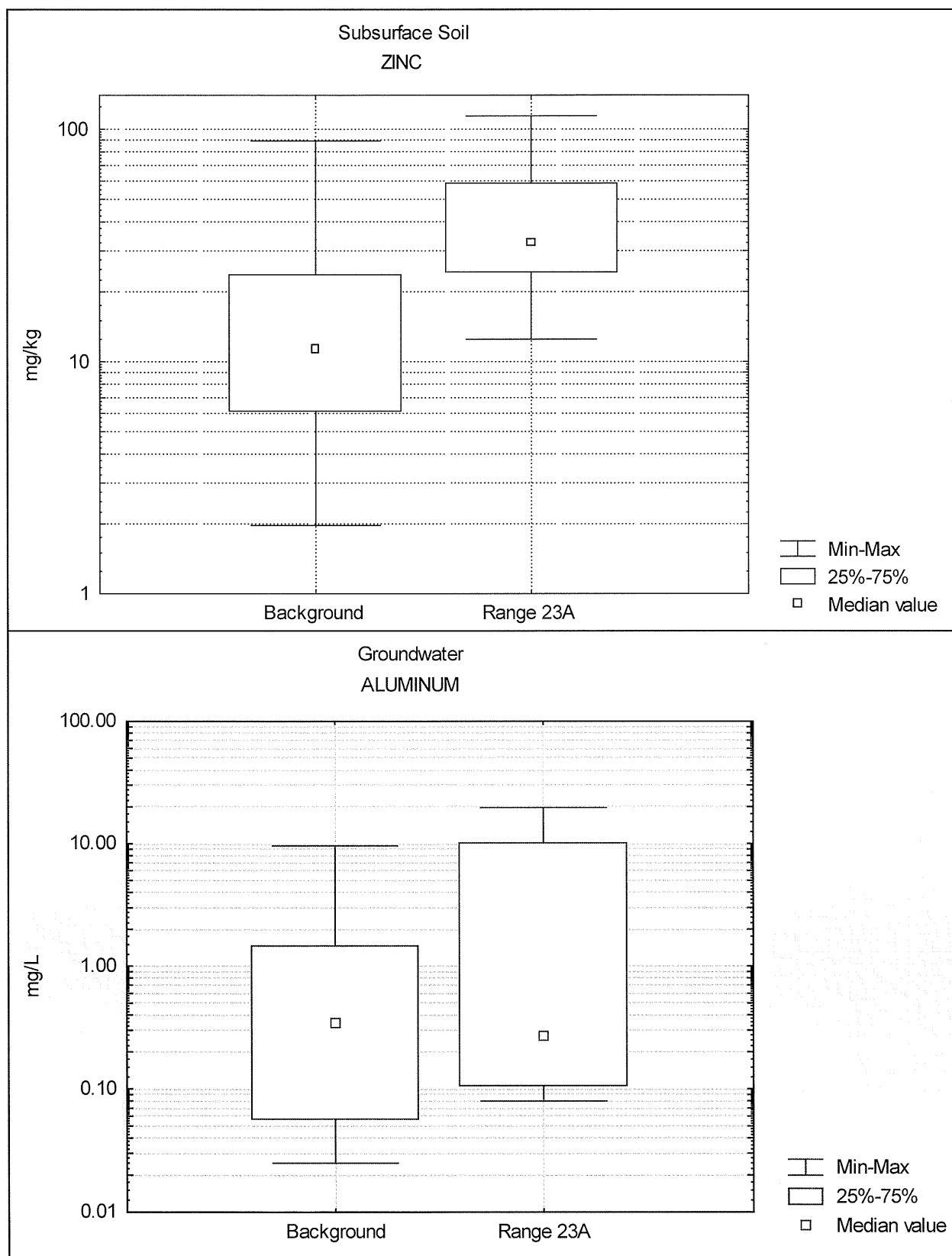


Figure 1-14

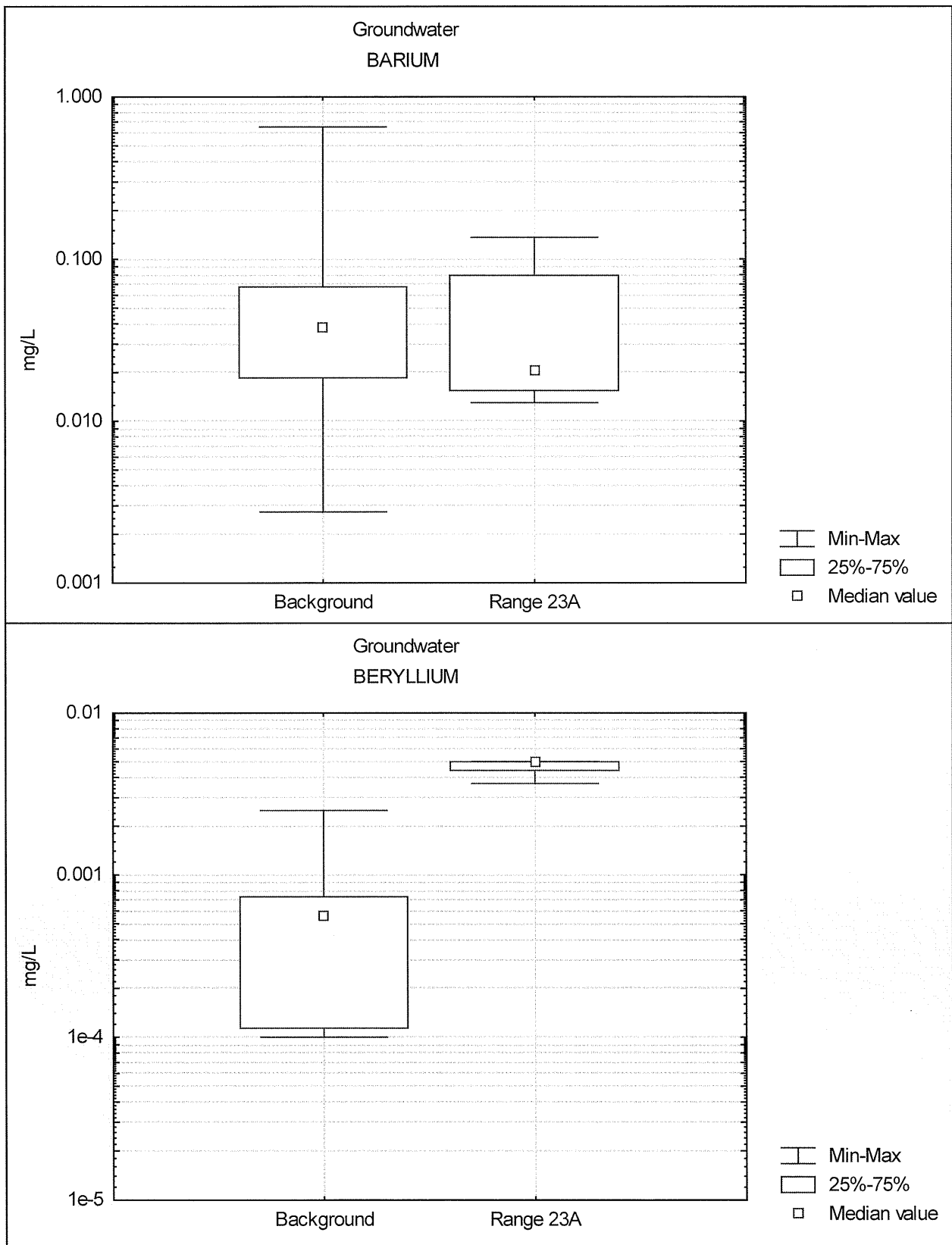


Figure 1-15

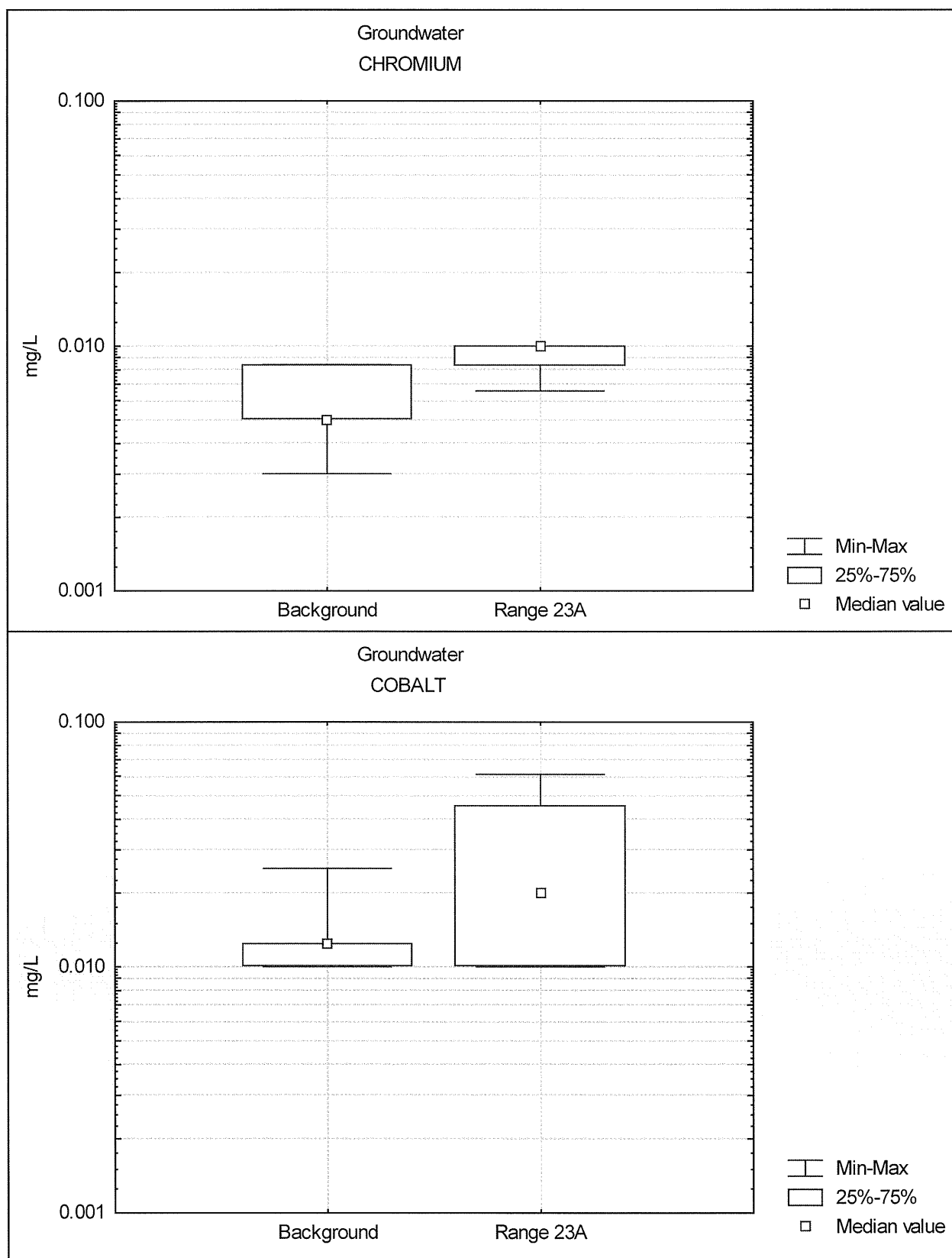


Figure 1-16

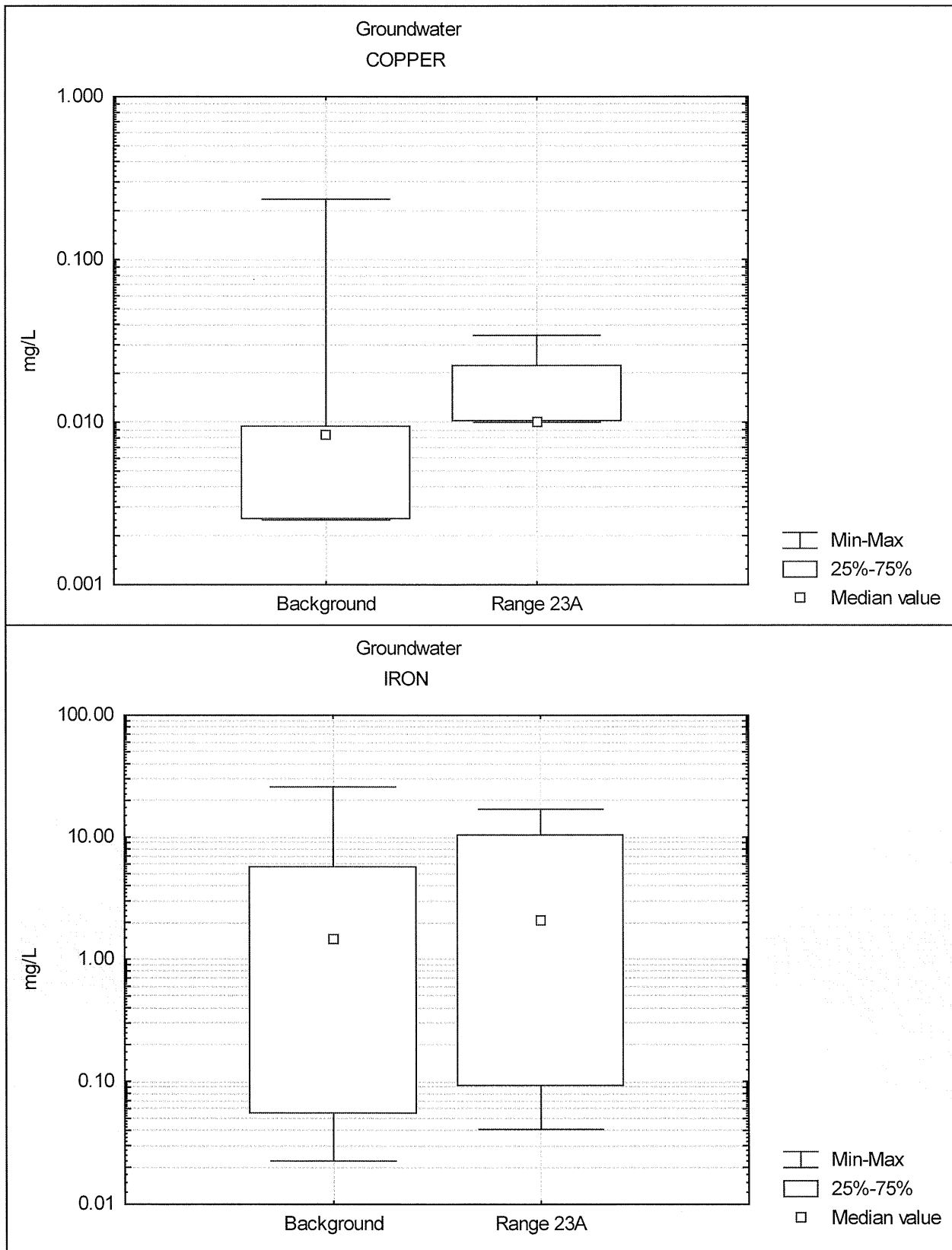


Figure 1-17

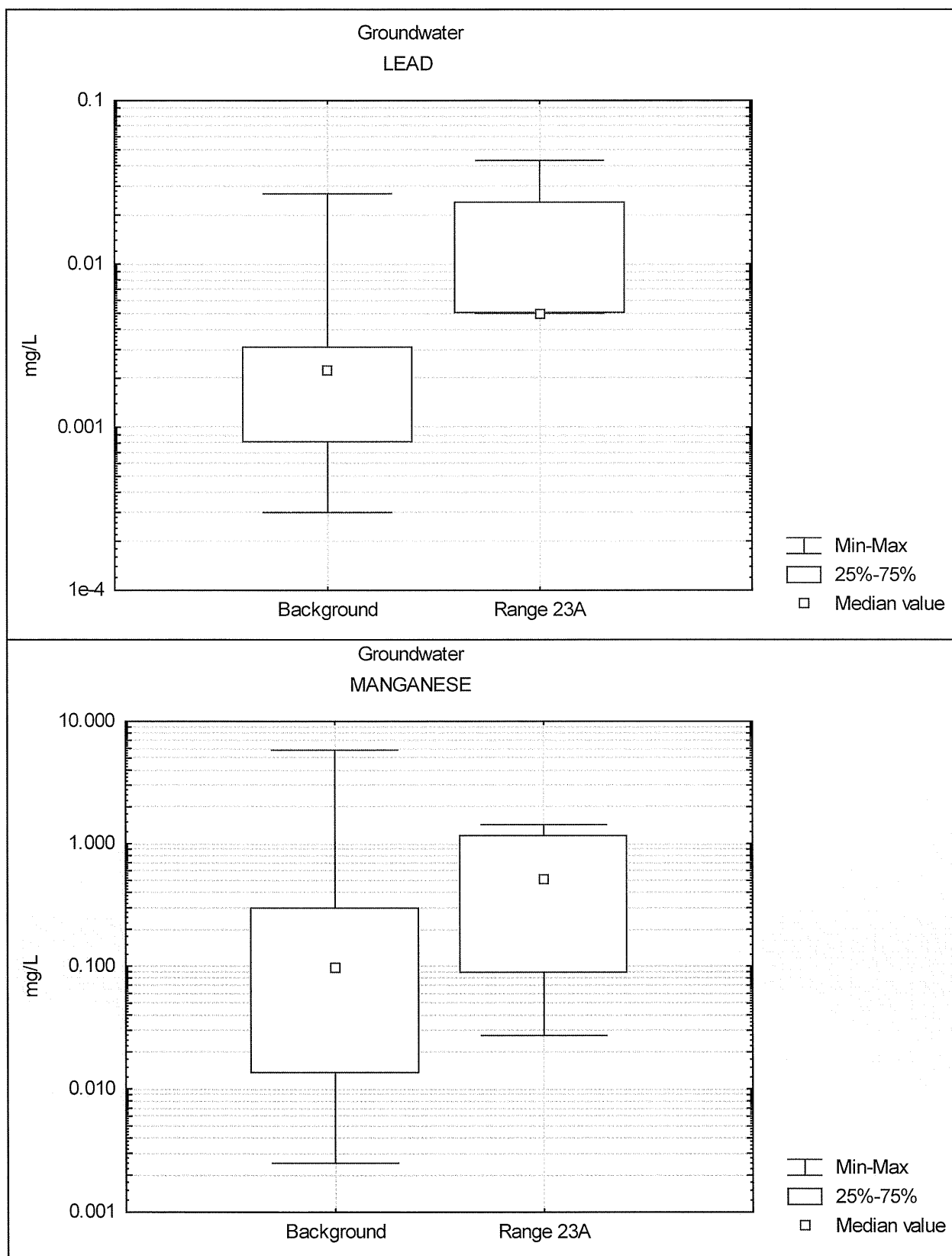


Figure 1-18

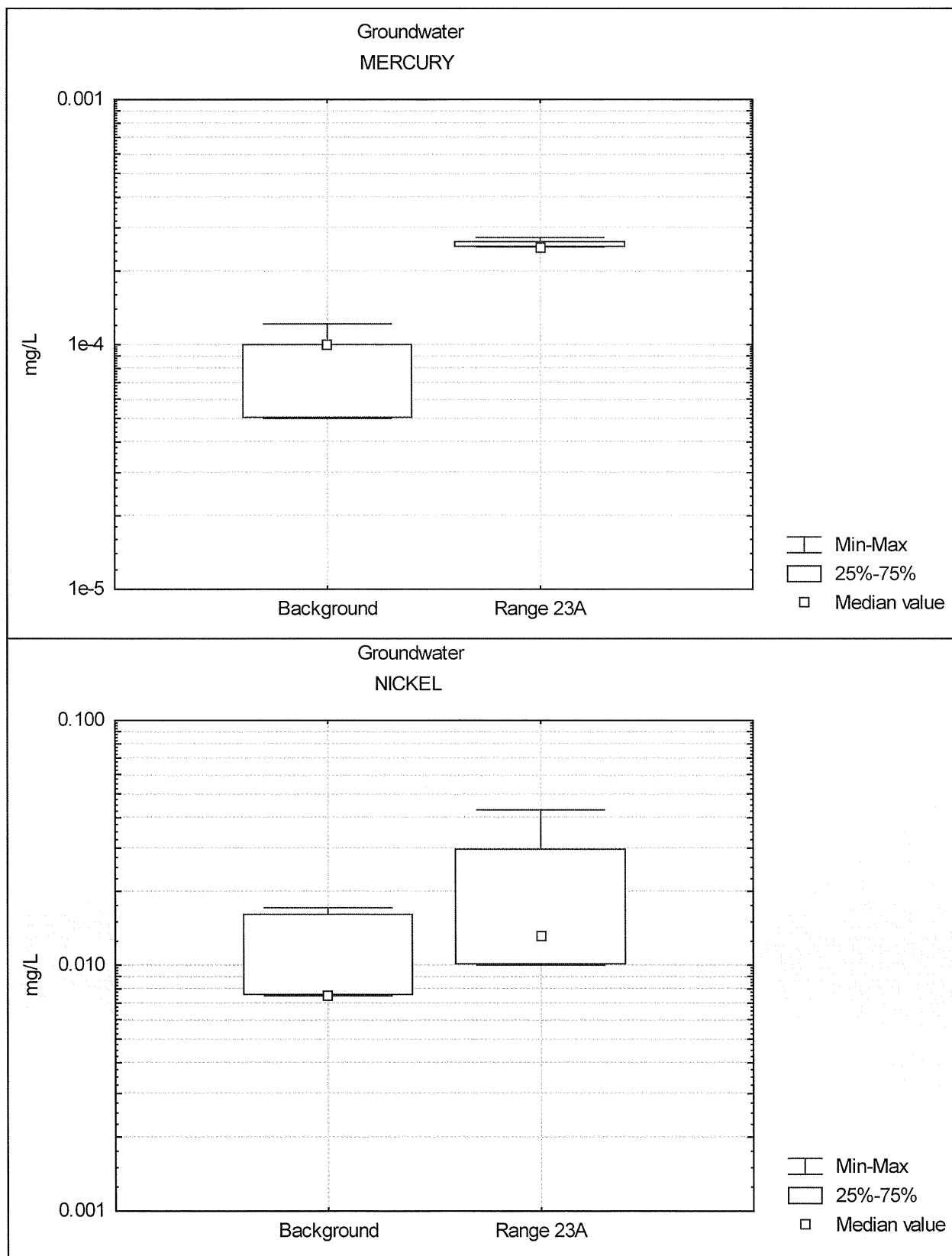


Figure 1-19

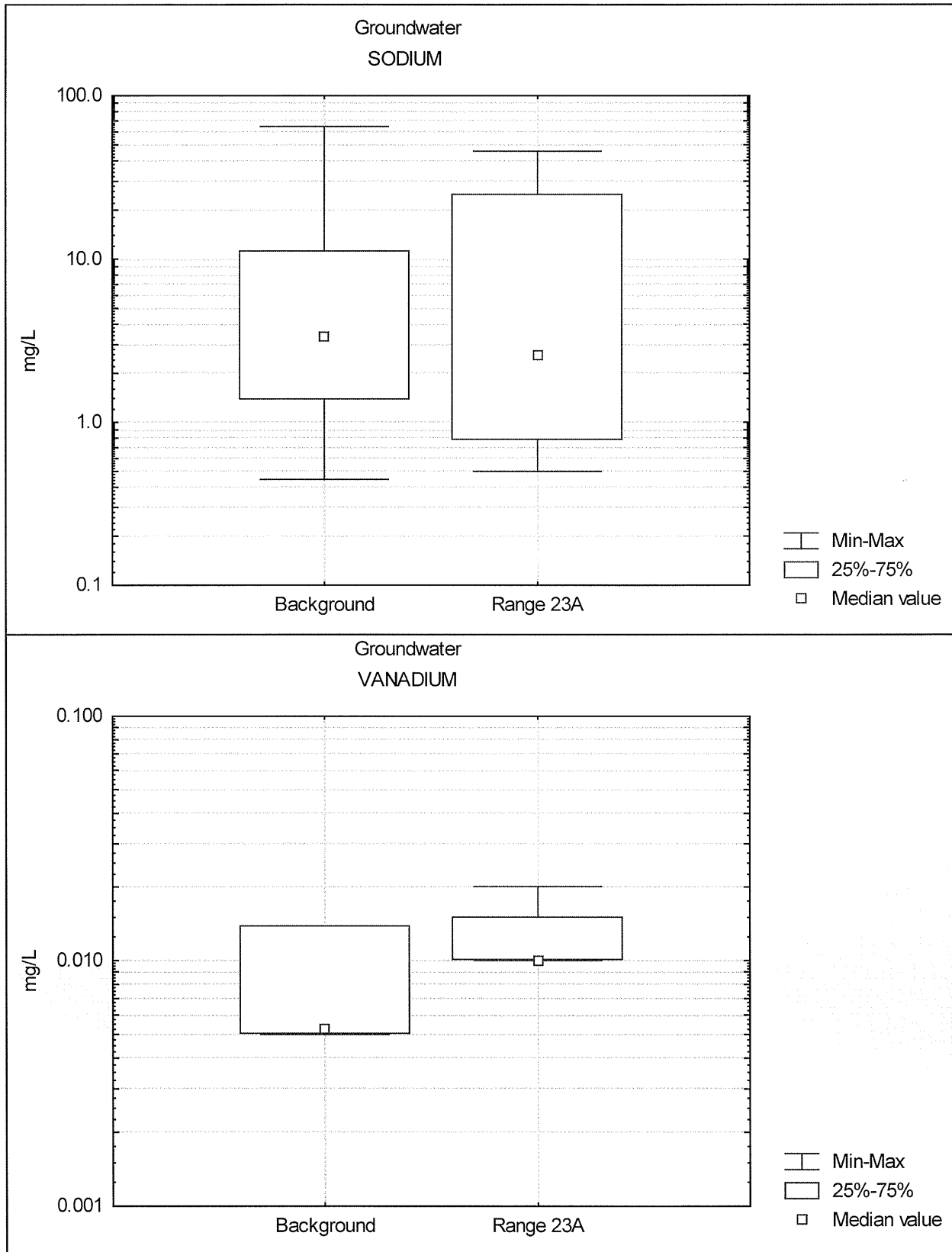


Figure 1-20

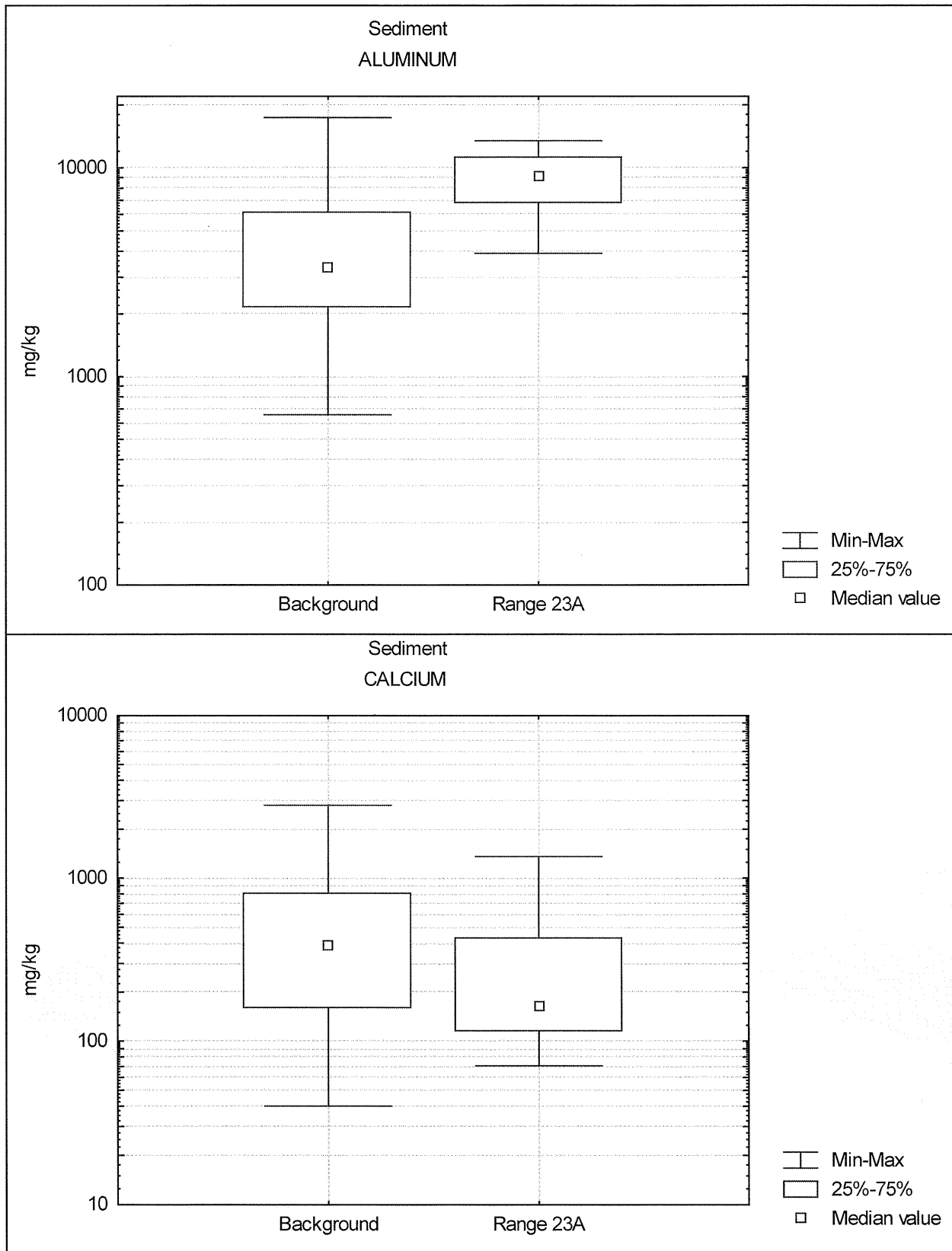


Figure 1-21

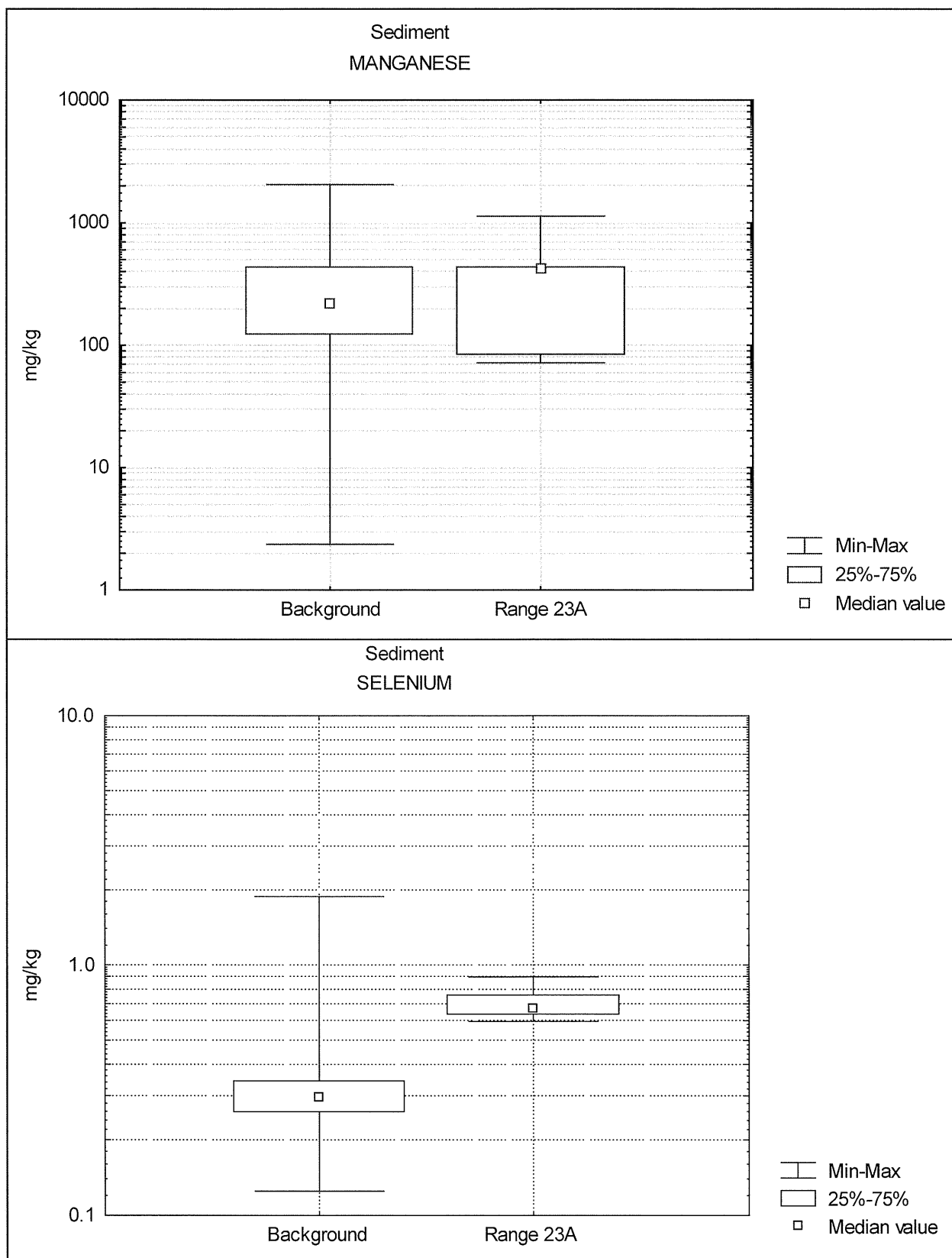
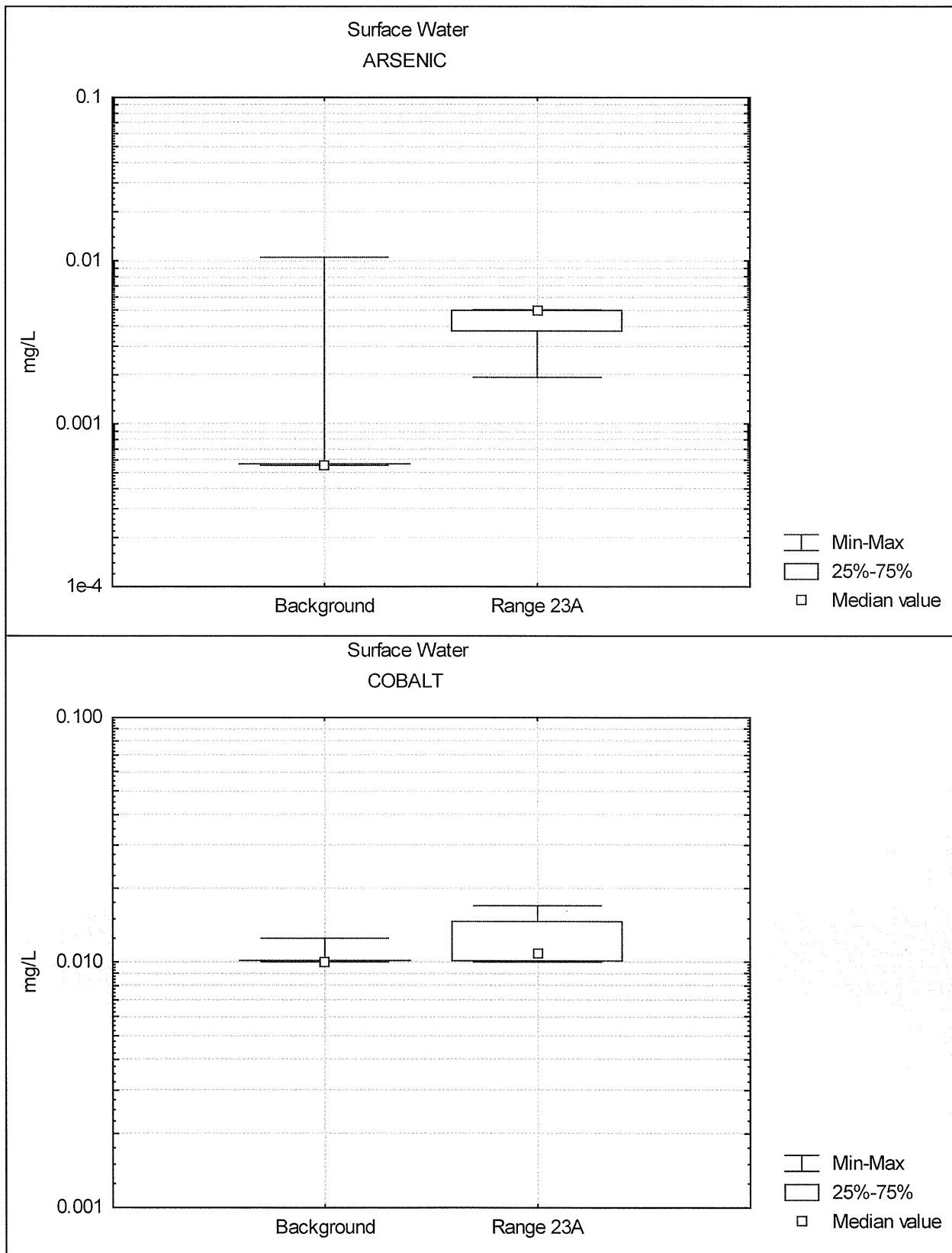


Figure 1-22



**GEOCHEMICAL
(TIER III)**

Geochemical Evaluation of Metals in Soil, Sediment, Groundwater, and Surface Water Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X Fort McClellan, Alabama

1.0 Introduction

This report provides the results of a geochemical evaluation of inorganic constituents in soil, sediment, groundwater, and surface water samples from Range 23A, Multipurpose Range, Parcel 109(7)/152Q-X, at Fort McClellan in Calhoun County, Alabama. Nine elements in soil, one element in sediment, four elements in groundwater, and one element in surface water failed statistical comparison to background. A geochemical evaluation was performed to determine if the elevated concentrations are naturally occurring or if they contain a component of contamination.

Site samples included in the evaluation consist of eleven surface soil samples (obtained from a depth of 0 to 1 foot below ground surface [bgs]) collected in November 2001; eleven subsurface soil samples (various depths ranging from 2 to 12 feet bgs) collected in November 2001; six sediment samples collected in February 2002; four unfiltered groundwater samples collected in February and March 2002; and six unfiltered surface water samples collected in February 2002. Installation-wide background data for TAL metals in soil, sediment, groundwater, and surface water are provided in the background study report (Science Applications International Corporation, 1998) and are used in the following evaluation.

2.0 Geochemical Evaluation Methodology

Naturally occurring trace element concentrations in environmental media commonly exceed regulatory screening criteria. Trace element distributions in uncontaminated soil tend to have very large ranges (two to three orders of magnitude are not uncommon), and are highly right-skewed, resembling lognormal distributions. These trace elements are naturally associated with specific soil-forming minerals, and the preferential enrichment of a sample with these minerals will result in elevated trace element concentrations. It is thus important to be able to identify these naturally high concentrations and distinguish them from potential contamination.

If an analyte fails statistical comparison to background as described in the “Statistical Comparison of Site and Background Data for Range 23A,” then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The

importance of geochemical evaluations in distinguishing between site and background data sets has been recognized in the industry (U.S. Environmental Protection Agency, 1995; Barclift, *et al.*, 2000; U.S. Navy, 2002; Myers and Thorbjornsen, 2004). When properly evaluated, geochemistry can provide mechanistic explanations for apparently high, yet naturally occurring, constituents. Anomalous samples that may represent contamination can also be readily distinguished from uncontaminated samples. This section describes the geochemical evaluation techniques that were employed in the site-to-background comparisons for Range 23A.

It should be noted that the geochemical evaluations rely in part on professional judgment and qualitative assessment is a necessary part of the process. Samples that plot off the linear trend on a correlation plot are certainly suspect, but because all uncertainty cannot be eliminated from the evaluation, such plots cannot be construed as definitive proof of contamination. However, anomalous samples should be flagged as suspect and their results used as a basis for further investigation, risk assessment, or remediation, as appropriate. The combination of statistical evaluations (Tiers 1 and 2) and geochemical evaluation (Tier 3) as presented in this appendix is effective in reducing the occurrences of decision errors relative to consideration of statistics or geochemistry alone.

2.1 Soil and Sediment

The geochemical evaluation is based on the natural associations of trace elements with specific minerals in the soil or sediment matrix. As an example, arsenic in most uncontaminated oxic soils is almost exclusively associated with iron oxide minerals (Bowell, 1994; Schiff and Weisberg, 1997). (The term “iron oxide” is used here to include oxides, hydroxides, oxyhydroxides, and hydrous oxides of iron.) This association of arsenic with iron oxides is a result of the adsorptive behavior of this particular trace metal in an oxic soil environment. Arsenic is present in oxic soil pore fluid as negatively charged oxyanions (HAsO_4^{-2} , H_2AsO_4^-) (Brookins, 1988). These anions have strong affinities to adsorb on the surfaces of iron oxides, which maintain a strong positive surface charge (Electric Power Research Institute, 1986). If a soil sample has a high percentage of iron oxides, then it is expected to have a proportionally higher concentration of arsenic.

The absolute concentrations of arsenic and iron can vary by several orders of magnitude at a site, but the arsenic/iron ratios in the samples are usually quite constant as long as no contamination is present (Daskalakis and O'Connor, 1995). If a sample has some naturally occurring arsenic plus additional arsenic from an herbicide or some other source, then it will have an anomalously high

ratio relative to the other uncontaminated samples. These ratios thus serve as a powerful technique for identifying contaminated samples.

The evaluation includes the generation of plots in which detected arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding detected iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic/iron background ratio. If the samples with the highest arsenic concentrations plot on the same linear trend as the other samples, then it is most probable that the elevated concentrations are natural, and are caused by the preferential enrichment of iron oxides in those samples. If the site samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix. Vanadium and selenium, along with arsenic, form anionic species in solution and are associated with iron oxides, which maintain a positive surface charge. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces, which maintain a negative surface charge. These trace elements would be evaluated against aluminum, which is a major component of clay minerals. Manganese oxides also have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). These trace elements would be evaluated against manganese.

2.2 Groundwater and Surface Water

Elevated concentrations of inorganic constituents in groundwater and surface water samples may be due to naturally high dissolved concentrations, the presence of suspended particulates in the samples, reductive dissolution, or contamination resulting from site activities. This section discusses the major geochemical processes considered during the evaluation of groundwater and surface water analytical data.

Effects of Suspended Particulates. The presence of trace elements adsorbed on suspended particulates can greatly increase trace element concentrations as reported by an analytical laboratory. These adsorbed trace elements are not in true solution, and can be removed by settling or filtration. The same concepts involved in the evaluation of soil and sediment data also apply to groundwater and surface water data: samples containing trace elements adsorbed on suspended clay particulates should show a positive correlation with aluminum concentrations, and samples containing trace elements adsorbed on suspended iron oxides should show a

positive correlation with iron concentrations. These correlations are evaluated by generating x-y plots of the concentrations of an elevated trace metal versus aluminum or iron (depending on the trace element).

The most common suspended particulates in groundwater samples are clay minerals; hydrous aluminum oxides ($\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$) and hydroxides [$\text{Al}(\text{OH})_3$]; and iron oxide (Fe_2O_3), iron hydroxide [$\text{Fe}(\text{OH})_3$], and iron oxyhydroxide ($\text{FeO} \cdot \text{OH}$) minerals, collectively referred to as “iron oxides.” All clay minerals contain aluminum and have low solubilities over a neutral pH range of 6 to 8. Measured concentrations of aluminum in excess of ~1 milligram per liter (mg/L) indicate the presence of suspended clay minerals (Hem, 1985; Stumm and Morgan, 1996), with higher aluminum concentrations being a qualitative indicator of the mass of suspended clay minerals. Iron also has a very low solubility under neutral pH and moderate to oxidizing redox conditions, so that measured iron concentrations in excess of ~1 mg/L under these conditions indicate the presence of suspended iron oxides (Hem, 1985).

The presence of suspended clay or iron oxides in groundwater samples has particular importance in the interpretation of trace element concentrations. Most clay particles maintain a negative surface charge under neutral pH conditions, and have a strong tendency to adsorb positively charged (cationic) aqueous species. Iron oxides display the opposite behavior, maintaining a positive surface charge under neutral pH conditions, and have a strong tendency to adsorb negatively charged (anionic) aqueous species.

Barium, lead, and zinc are usually present in groundwater as divalent cations and thus tend to concentrate on clay surfaces (Electric Power Research Institute, 1984; Brookins, 1988). Arsenic, selenium, and vanadium are usually present under oxidizing conditions as oxyanions, and thus tend to concentrate on iron oxide surfaces (Bowell, 1994; Hem, 1985; Pourbaix, 1974; Brookins, 1988).

Chromium can be present in groundwater as a mixture of aqueous species with different charges, depending on pH (Electric Power Research Institute, 1984). The positive, neutral, and negative charges on these species result in the distribution of chromium on several different types of sorptive surfaces, including clay and iron oxide minerals.

As an example, the concentrations of zinc (y-axis) would be plotted against aluminum (x-axis). If all of the samples display a common linear trend, then it is most likely that the zinc concentrations are due to the presence of suspended clay minerals in the samples. The slope of a

best-fit line through the points is equal to the average zinc/aluminum ratio. If some samples plot above the linear trend established by the other samples, then those samples have an anomalously high zinc/aluminum ratio, and most likely contain excess zinc that cannot be explained by these natural processes.

Alternative techniques for assessing the effects of suspended particulates on trace element concentrations are the evaluation of correlations of trace element concentrations versus turbidity, and comparison of analyses of filtered versus unfiltered splits of samples. Turbidity measurements are qualitative, and do not distinguish between suspended clay minerals, iron oxides, and natural organic material, so this approach lacks the resolution provided by trace element versus aluminum or trace element versus iron correlations.

If the concentrations of trace elements in unfiltered samples are correlated with aluminum or iron, then they are most likely adsorbed to the surfaces of suspended particulates. If these correlations are linear, then the elevated concentrations are most likely natural.

Effects of Reductive Dissolution. Iron and manganese oxides concentrate several trace elements such as arsenic, selenium, and vanadium on mineral surfaces, as discussed above. In soils and sedimentary aquifers, these elements are almost exclusively associated with iron and manganese oxide minerals and grain coatings, as long as the redox conditions are moderate to oxidizing.

The release of organic contaminants such as fuels or chlorinated solvents can establish local reducing environments caused by anaerobic microbial degradation of the organic compounds. The establishment of local reducing conditions can drive the dissolution of iron and manganese oxides, which become soluble as the redox potential drops below a threshold value. Dissolution of these oxide minerals can mobilize the trace elements that were adsorbed on the oxide surfaces, which is a process termed “reductive dissolution.” Several investigations have documented the mobilization of arsenic, selenium, and other trace elements under locally reducing redox conditions (Sullivan and Aller, 1996; Nickson, *et al.*, 2000; Belzile, *et al.*, 2000).

Evidence for reductive dissolution would be a correlation between elevated trace elements (arsenic, selenium, and vanadium in particular) versus lower redox conditions. Low redox conditions can be identified by local depressions in oxidation-reduction potential (ORP) or dissolved oxygen (DO) measurements, or the presence of reducing gases such as hydrogen, methane, ethane, or ethene. Anaerobic microbes can also reduce sulfate to sulfide and nitrate to

ammonia, resulting in local depressions in sulfate and nitrate concentrations, and local detections of sulfide and ammonia. In areas impacted by chlorinated solvents, additional evidence for the establishment of anaerobic reducing conditions is the presence of *cis*-1,2-dichloroethene and/or vinyl chloride, which are reductive dechlorination products resulting from the microbial degradation of trichloroethene or tetrachloroethene under anaerobic conditions.

3.0 Results of the Geochemical Evaluation for Multiple Elements in Soil

This section presents the results of the geochemical evaluation of arsenic, cadmium, copper, magnesium, mercury, potassium, selenium, silver, and zinc in soil samples from Range 23A. Correlation plots are provided in Attachment 1.

Arsenic

As discussed in Section 2.1, arsenic in oxic soils has a strong affinity to adsorb on iron oxides. A positive correlation between arsenic and iron is expected for uncontaminated samples under those conditions. A plot of arsenic versus iron reveals a common linear trend with a positive slope for the site and background samples (Figure 1). The site samples with high arsenic concentrations generally contain proportionally higher iron, and lie on the linear trend. These observations indicate that arsenic in the site samples is associated with iron oxides at a relatively constant ratio, and is natural.

Conclusion

Arsenic detected in the site soil samples is naturally occurring.

Cadmium

Cadmium is commonly present in soils as a divalent cation, and has an affinity to adsorb on manganese oxides (Kabata-Pendias, 2001). A positive correlation between cadmium and manganese is thus expected in uncontaminated samples. The background samples form a generally linear trend with a positive slope in a plot of cadmium versus manganese, and the two site samples with detectable cadmium lie on or slightly above this trend (Figure 2). Subsurface soil sample NH0004 contains the higher cadmium concentration (0.917 mg/kg) of the two site samples, and lies slightly above the linear trend formed by the other samples. This result is an estimated concentration below the reporting limit of 1.24 mg/kg, and there is a high degree of uncertainty associated with such values. The site samples are characterized by lower reporting limits relative to the background samples: site reporting limits range from 1.08 to 1.25 mg/kg, with a mean and median of 1.18 mg/kg, whereas the background reporting limits for the nondetects range from 0.015 to 4.01 mg/kg, with a mean of 0.427 mg/kg and median of 0.054 mg/kg (reporting limit data are unavailable for the background detections). The uncertainty associated with estimated concentrations and the difference in reporting limits between the two data sets likely explains the slightly higher Cd/Mn ratio exhibited by sample NH0004. All of these observations indicate that cadmium in the site samples is naturally occurring.

Conclusion

Cadmium detected in the site soil samples is naturally occurring.

Copper

Copper in soil has an affinity to adsorb on the surfaces of minerals such as clays and iron oxides (Kabata-Pendias, 2001). Most of the site and background samples form a linear trend with a positive slope in a plot of copper versus iron (Figure 3). Most of the site samples with high copper concentrations also exhibit proportionally higher iron, and lie on the background trend. Copper in these samples is associated with iron oxides at a relatively constant ratio, and is natural.

There are four subsurface soil samples that contain high copper (19.9 to 40.6 mg/kg) but moderate iron, and lie above the trend formed by most of the background samples. These samples were obtained from depths of 7 feet bgs or greater; they do not contain organic compound contamination or elevated lead or zinc, and their soil boring logs note nothing unusual about the soil at these depths. Furthermore, there are three background samples that exhibit similarly high Cu/Fe ratios and which lie above the linear trend – including the background sample with the maximum detected concentration of 60.9 mg/kg, which was collected from a depth of 7 feet bgs. These four site samples and three background samples most likely reflect the natural variability in Cu/Fe ratios in Ft. McClellan soils. Copper in these site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

Conclusion

Copper detected in the site soil samples is naturally occurring.

Magnesium

Magnesium is a common component of minerals such as clays and micas, which contain aluminum as a primary constituent, so positive correlations between magnesium and aluminum concentrations in soil are often observed. A plot of magnesium versus aluminum reveals a generally linear trend for most of the background samples, and the site samples lie on this trend (Figure 4). The site samples with high magnesium concentrations also exhibit proportionally higher aluminum content. These observations indicate a natural source for the elevated magnesium in the site samples.

Conclusion

Magnesium detected in the site soil samples is naturally occurring.

Mercury

Mercury concentrations in soil are commonly controlled through organic complex formation (Kabata-Pendias, 2001), so weak correlations between mercury and iron or mercury and aluminum are often observed, even in uncontaminated soil samples. The background samples form a generally linear trend with a positive slope in a plot of mercury versus aluminum (Figure 5). The site samples all lie on this trend. Mercury in the site samples is associated with clays at ratios consistent with those of the background samples, and is natural.

Conclusion

Mercury detected in the site soil samples is naturally occurring.

Potassium

Potassium is a major element that is a common constituent of minerals such as clays, which also contain aluminum. Most of the background samples form a generally linear trend in a plot of potassium versus aluminum, and the site samples lie on this trend (Figure 6). The site samples with high potassium have proportionally higher aluminum – or at least exhibit K/Al ratios similar to the background K/Al ratios – and lie on the trend established by the other samples. This indicates that potassium in the site samples is associated with clays and other aluminum-bearing minerals at ratios consistent with those of the background samples, and that the potassium is natural.

Conclusion

Potassium detected in the site soil samples is naturally occurring.

Selenium

As explained in Section 2.1, selenium has a strong affinity to adsorb on iron oxides in oxic soils, so a positive correlation between selenium and iron is expected for uncontaminated soil samples. Comparison to background is hindered because of the high percentage of nondetects in the background data set. A plot of selenium versus iron is provided in Figure 7. The single subsurface soil sample on the plot contains the highest selenium concentration of the site and background data sets (1.75 mg/kg), but it also contains proportionally higher iron. This indicates that the sample is preferentially enriched in iron oxides and associated trace elements, and that the selenium is natural. The four selenium concentrations detected in the surface soil samples exhibit low variability, ranging from 0.669 J to 0.704 J mg/kg. These four results are estimated values below the reporting limit (the reporting limits range from 1.1 to 1.25 mg/kg), and such values are highly uncertain. This uncertainty likely explains why the four site surface samples form a linear trend with a shallow slope. However, these four samples are well below the background maximum of 1.28 mg/kg. All of these observations indicate a natural source for selenium in the site samples.

Conclusion

Selenium detected in the site soil samples is naturally occurring.

Silver

A plot of silver versus iron is provided in Figure 8. The site samples with detectable silver have higher concentrations than most of the background samples, but they are also characterized by high iron. It is likely that these site samples are preferentially enriched in iron oxides and associated trace elements, and that the silver is natural. It is important to note that all twelve site detections are estimated (“J”-qualified) values below the reporting limit, and that such values are highly uncertain. In comparison, the background detections are mostly unestimated concentrations ranging from 0.019 to 1.87 mg/kg, with a mean of 0.128 mg/kg (14 of the 82 background samples are estimated values). Additionally, the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits range from 2.16 to 2.51 mg/kg, with a mean of 2.36 mg/kg, whereas the reporting limits for the background

nondetects range from 0.016 to 1.2 mg/kg, with a mean of 0.293 mg/kg [reporting limit data are unavailable for the background detected concentrations]. The uncertainty associated with the estimated site concentrations, combined with the difference (up to two orders of magnitude) in reporting limits between the data sets, likely explains why the site samples do not exhibit the same Ag/Fe ratios exhibited by most of the background samples.

Conclusion

Silver detected in the site soil samples is naturally occurring.

Zinc

Zinc commonly substitutes for magnesium in silicate minerals (Kabata-Pendias, 2001), so a positive correlation between zinc and magnesium would be expected for uncontaminated samples. A plot of zinc versus magnesium is provided in Figure 9. The site and background samples form a common linear trend with a positive slope. Most of the site samples with high zinc also contain proportionally higher magnesium, and lie on the linear trend. This indicates a natural source for zinc in these samples.

There are three subsurface soil samples that contain elevated zinc (58.3 to 114 mg/kg) but moderate magnesium, and which lie slightly above the trend formed by most of the background samples. These samples were obtained from depths of 7 feet bgs or greater; they do not contain organic compound contamination or elevated copper or lead, and their soil boring logs note nothing unusual about the soil at these depths. Furthermore, there are several background samples that exhibit similarly high Zn/Mg ratios – including the background sample with the maximum detected concentration of 209 mg/kg. These samples most likely reflect the natural variability in Zn/Mg ratios in Ft. McClellan soils. Zinc in the site samples is associated with magnesium-bearing minerals at ratios consistent with those of the background samples, and is natural.

Conclusion

Zinc detected in the site soil samples is naturally occurring.

4.0 Results of the Geochemical Evaluation for Aluminum in Sediment

This section presents the results of the geochemical evaluation of aluminum in sediment samples from Range 23A. Correlation plots are provided in Attachment 1.

Aluminum

Aluminum is a primary component of common minerals such as clays, feldspars, and micas. Iron oxides are minerals that are also common in sediment. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. A plot of aluminum versus iron concentrations can be used to qualitatively assess the relative abundance of these minerals in site sediment (Figure 10). The site samples exhibit higher aluminum concentrations than many of the background samples, but they lie on the linear background trend. This suggests that the site samples are naturally enriched in clays relative to most of the background samples, and that the aluminum is natural.

Conclusion

Aluminum detected in the site sediment samples is naturally occurring.

5.0 Results of the Geochemical Evaluation for Multiple Elements in Groundwater

This section presents the results of the geochemical evaluation of aluminum, cobalt, mercury, and nickel in the four unfiltered groundwater samples from Range 23A. Correlation plots are provided in Attachment 1.

Field-measured pH readings for the site groundwater samples range from 4.40 to 6.89 standard units, with a mean of 5.33. These values indicate slightly acidic conditions at most of the groundwater sample locations. Field-measured DO readings range from 1.96 to 7.36 mg/L, with a mean of 4.96 mg/L, and ORP readings range from +62 to +371 millivolts (mV), with a mean of +235 mV. These values suggest oxidizing conditions at the sample locations. Turbidity measurements range from 1.2 to 1000 nephelometric turbidity units (NTU), with a mean of 252 NTU and a median of 4.25 NTU. Although one site sample (NH3004, collected from monitoring well RNG-109-MW04) contained a significant mass of suspended particulates (turbidity of 1000 NTU), the other samples did not (turbidity of 4.4 NTU or lower). It should be noted that field readings are not available for the background samples.

Aluminum

Aluminum was detected in all four site groundwater samples, with concentrations ranging from 0.0798 J to 19.7 mg/L. As discussed previously, aluminum concentrations in excess of approximately 1 mg/L in neutral pH groundwater indicate the presence of suspended clays. Aluminum will be present in solution at a pH below about 4.0, but the Range 23A pH readings are higher than this. The detectable aluminum in the site samples is thus primarily associated with suspended particulates.

Iron concentrations in excess of approximately 1 mg/L in neutral-pH, moderate to oxidizing groundwater conditions indicate the presence of suspended iron oxides. A plot of aluminum versus iron permits a qualitative assessment of the amount of suspended particulates in the groundwater samples (Figure 11). A strong linear trend with a positive slope is typically observed when the aluminum and iron are both present in particulate form. Just such a trend is observed here for most of the site and background samples. The site sample (NH3004) with the highest aluminum concentration exhibits proportionally higher iron, and lies on the linear trend formed by the other samples. This indicates that the elevated aluminum is due to the presence of suspended clay particulates, and is natural. This conclusion is corroborated by the field-measured turbidity reading of 1000 NTU for sample NH3004, which indicates a significant mass of suspended particulates.

The site sample with the lowest aluminum concentration (NH3002; 0.0798 J mg/L) exhibits moderately high iron (4 mg/L), and lies below and to the right of the particulate trend. There are also three background samples with similarly low Al/Fe ratios. The iron in these samples is likely in solution due to low redox conditions (sample NH3002 has the lowest DO reading of the site data set). The aluminum concentration in sample NH3002, however, is well within the background range.

Conclusion

Aluminum detected in the site groundwater samples is naturally occurring.

Cobalt

Cobalt was detected in two of the four site groundwater samples. Comparison to background is hindered by the high percentage of nondetects in both data sets. However, a plot of detected cobalt versus detected iron concentrations reveals a linear trend with a positive slope for the two site samples and one of the background samples (Figure 12). The site sample with the highest cobalt concentration (NH3004; 0.0611 mg/L) also contains the highest iron concentration of the site data set (16.9 mg/L). This sample also contains the highest aluminum concentration of both data sets (19.7 mg/L) and the highest turbidity (1000 NTU) of the four site samples. The field readings for this sample indicate oxidizing, neutral-pH conditions at the time of sample collection, so the iron and aluminum are both expected to be present primarily as suspended particulates such as iron oxides and clays, which have an affinity to adsorb trace elements such as cobalt. All of these observations suggest that cobalt in the site samples is associated with suspended particulates at a relatively constant ratio, and that the cobalt is natural.

Conclusion

Cobalt detected in the site groundwater samples is naturally occurring.

Mercury

Evaluation is hindered by the high percentage of nondetects in both site and background data sets (75 and 100 percent, respectively). However, the single site sample (NH3004) with detectable mercury contains the highest iron concentration of the site samples (16.9 mg/L), as well as the highest aluminum concentration of both data sets (19.7 mg/L) and the highest turbidity (1000 NTU) of the four site samples. The field readings for this sample indicate oxidizing, neutral-pH conditions at the time of sample collection, so the iron and aluminum are both expected to be present primarily as suspended particulates such as iron oxides and clays, which have an affinity to adsorb trace elements such as mercury. The mercury detected in sample NH3004 is most likely sorbed on these suspended particulates, and is natural.

Conclusion

Mercury detected in the site groundwater samples is naturally occurring

Nickel

Nickel was detected in two of the four site groundwater samples. Comparison to background is hindered by the high percentage of nondetects in the background data set. However, a plot of nickel versus iron reveals a linear trend with a positive slope for the two site samples and single background sample with detectable nickel (Figure 13). Site sample NH3004 contains the highest

nickel concentration (0.043 mg/L) but it also contains the highest iron concentration of the site samples (16.9 mg/L). This sample also contains the highest aluminum concentration of both data sets (19.7 mg/L). The field readings for this sample indicate oxidizing, neutral-pH conditions at the time of sample collection, so the iron and aluminum are both expected to be present primarily as suspended particulates such as iron oxides and clays, which have an affinity to adsorb trace elements such as nickel. All of these observations suggest that nickel in the site samples is associated with suspended particulates at a relatively constant ratio, and that the nickel is natural.

Conclusion

Nickel detected in the site groundwater samples is naturally occurring

6.0 Results of the Geochemical Evaluation for Arsenic in Surface Water

This section presents the results of the geochemical evaluation of arsenic in the six unfiltered surface water samples from Range 23A. Correlation plots are provided in Attachment 1.

Field-measured pH readings for the site surface water samples range from 5.05 to 6.73 standard units, with a mean of 5.90. These values indicate neutral to slightly acidic conditions at the surface water sample locations. Field-measured DO readings range from 6.97 to 11.46 mg/L, with a mean of 9.71 mg/L. These readings suggest oxidizing conditions at the sample locations (ORP readings are not available). Turbidity measurements range from 8.3 to 96 NTU, with a mean of 58.9 NTU. These values indicate that the site samples did not contain a significant mass of suspended particulates. It should be noted that field readings are not available for the background samples.

Arsenic

Arsenic was detected in two of the six site surface water samples. As discussed previously, under natural conditions arsenic is present in waters primarily as oxyanions and its concentrations are often controlled by adsorption on iron oxides. A plot of detected arsenic concentrations versus detected iron concentrations is provided in Figure 14. The site samples and most of the background samples form a common linear trend with a positive slope. The site sample with the higher of the two detected arsenic concentrations (NH2004) contains only a moderate amount of arsenic relative to the background samples (0.00363 mg/L, which is slightly below the mean value of 0.0038 mg/L for the background detections) as well as a proportional amount of iron, and lies near the center of the linear background trend. These observations indicate that the arsenic in the site samples is associated with suspended iron oxides at ratios consistent with those of the background samples, and is natural.

Conclusion

Arsenic detected in the site surface water samples is naturally occurring.

7.0 Summary

This section summarizes the results of the geochemical evaluations of selected elements in soil, sediment, groundwater, and surface water samples from Range 23A.

Soil. Geochemical evaluation indicates that all of the arsenic, cadmium, copper, magnesium, mercury, potassium, selenium, silver, and zinc concentrations detected in the site surface and subsurface soil samples are naturally occurring.

Sediment. Geochemical evaluation indicates that aluminum detected in the site sediment samples is naturally occurring.

Groundwater. Geochemical evaluation indicates that aluminum, cobalt, mercury, and nickel concentrations detected in the site groundwater samples are naturally occurring.

Surface Water. Geochemical evaluation indicates that arsenic detected in the site surface water samples is naturally occurring.

8.0 References

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ATTACHMENT 1

